Chemical Engineering Progress

PUBLISHED MONTHLY BY THE AMERICAN INSTITUTE OF CHEMICAL ENGINEERS

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Volume 48 Number 10

Chemical Engineering **Progress**

OCTOBER 1952

OPINION AND COMMENT Page THE FIRST HUNDRED YEARS 479 **ENGINEERING SECTION** SELLING-OPPORTUNITIES FOR CHEMICAL ENGINEERS IN CHEMICAL ENGLISH-A CHEMICAL ENGINEERING TOOL J. A. Field PRODUCTION OF METHANE FROM COAL-AN ECONOMIC STUDY L. S. Alberts, J. S. Bardin, D. W. Beery, H. R. Jones, and E. J. Vidt PRACTICAL THERMODYNAMICS **MECHANICS OF DROPS** R. R. Hughes and E. R. Gilliland SATURATION PERFORMANCE OF ION-EXCHANGE AND ADSORP-TION COLUMNS PRESSURE DROP IN ANNULI CONTAINING TRANSVERSE FIN TUBES F. W. Braun, Jr., and J. G. Knudsen 517 INDUSTRIAL VIEWPOINTS ON SEPARATION PROCESSES-Part I MARKETING RESEARCH... STATEMENT OF PURPOSE SOME ECONOMIC CHARACTERISTICS OF THE CHEMICAL FUNCTIONS OF CHEMICAL MARKET RESEARCH Parker Frisselle PLASTICS EQUIPMENT REFERENCE SHEET R. B. Seymour and R. H. Steiner 534 NEWS Page CLEVELAND MEETING 31 LETTERS TO THE EDITOR 60 CHICAGO MEETING 34 FUTURE MEETINGS 64 CENTENNIAL EXCERPTS 40 LOCAL SECTION DATA SERVICE43-46 CALENDAR OF MEETINGS. 65 INDUSTRIAL NEWS 50 NEWS ABOUT PEOPLE 68

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CLASSIFIED 74

NECROLOGY 76

MARGINAL NOTES 52

A.I.Ch.E. CANDIDATES 56 SECRETARY'S REPORT 59

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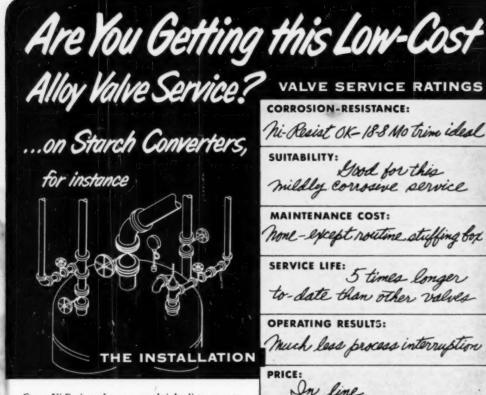


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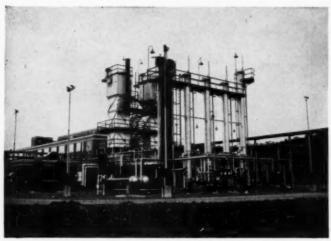
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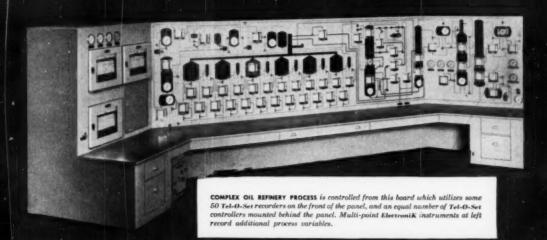
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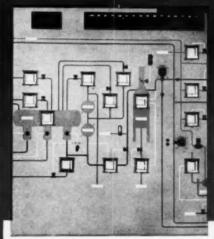
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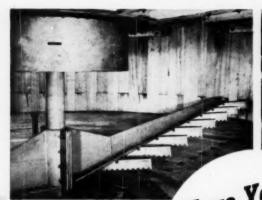
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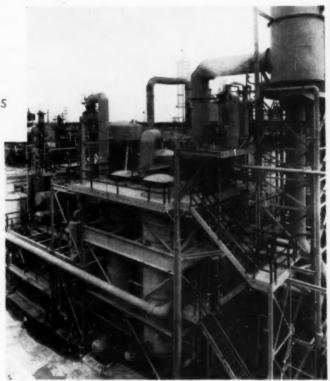
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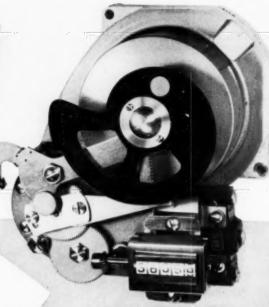


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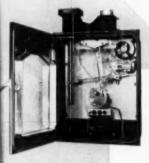
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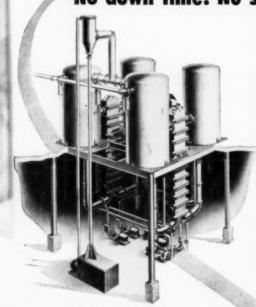
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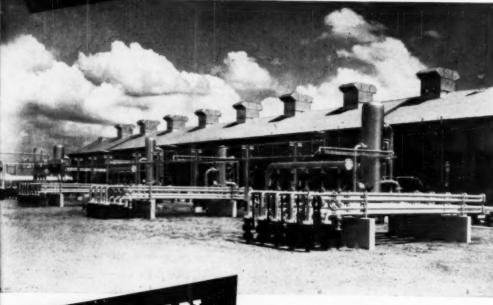
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for HILLS-MCCANNA saunders patent

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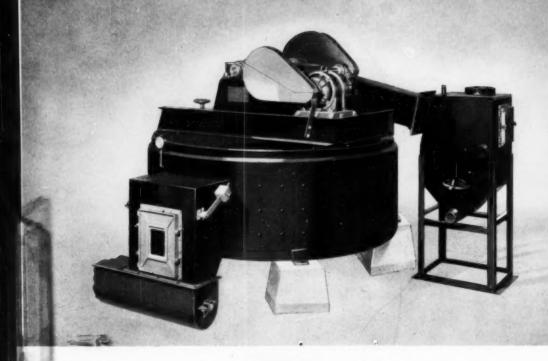
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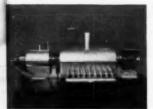
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saunders patent diaphragm valves

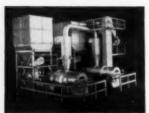
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"Builders of Equipment for People You Know"

CHEMICAL ENGINEERING-May 1952

THE (

NEW PROCESS-Ozone is being used more and hore in chemical processing to carry out difficult oxidaions. Not only is it used in the manufacture of artisone, but Emery Industries, Inc., of Cincinnati will

use ozone to oxidize oleic acid.

very has just been given the green light by the government to start construction of new \$2 million plant. It will be the world's largest single installation for the production of ozone. The ozone will be used in a new process, the result of joint research by Emery and Welsbach Corp of Philadelphia, for oxidation of oleic acid.

PRODUCTS-This new plant will greatly increase Emery's output of azeliac and pelargonic acids, the two

products that result from the oxidation of oleic acid.

Emery is now the sole producer of these two acids.

Now, because of the efficiency of the new ozone process, larger volumes of these acids will be produced, and at lower cost. In fact, azelaic acid will be next to the cheapest higher molecular weight dibasic acid on the market today. Likewise, pelargonic acid will be the cheapest monobasic alimhatic acid of its type.

ADVANTAGES-In addition to its increased efficiency, the new ozone process has other advantages. It eliminates the corrosion problem encountered in the present chromic acid oxidation. It gives higher yields of purer products. It's more versatile. In fact, it's expected that Emery's new unit will be able to use a broader selection of raw materials; this will mean a greater variety of end products, especially as other uses of this unique oxidation process are developed.

MARKETS—Interest in this development is

heightened by current investigations in the use of dibasic acids and their esters in synthetic lubricants for military and civilian uses. Such lubricants may consume much of the output of Emery's new plant.

Meantime, the use of azelaid acid in alkyds, as

as in plasticizers for vinyls, cellulosics and synic rubbers, can be expected to expand as costs come n. The markets in alkyds and plasticizers have been voved in the years Emery has operated its chromic oxidation plant. Only limited availability and relatively high price have curbed expansion in these fields. Now it will be possible to get the low-temperature performance of many esters of azelaic acid even in relatively low-cost plastic materials.

Emery's research points to growing use of azelaic acid as a raw material for polyamides of the nylon type. In polyamides, azelaic promises superior water

Pelargonic acid already has important uses that will resistance. grow as more of it comes on the market at lower cost. For example, more pelargonic will be used in flotation -where it's highly efficient but has been too costly up to now.

Another possibility is increased use of pelargonic acid in perfumes and fine chemicals. Actually, the name "pelargonic" comes from a botanical term asso-

ciated with geranium oil. sources-Amid current world tension, it's reassuring to know that oleic acid, the raw material for production of azelaic and pelargonic acids by the new ozone process, comes from animal fats and tallows. These are available in the U.S., and are currently in surplus supply. On the other hand, the closest counterpart of azelaic acid, one of the products, is sebacic acid, which is derived from castor oil, an imported raw

PRODUCTION—Emery's new plant is expected to material. be in operation within less than a year. By mid-1953 it will certainly be turning out azelaic and pelargonic acids by the new ozone process.

Nothing more need be said about

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e and versatility of WELSBACH OZONE . . . write now to

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Research Continuing



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steam, water, gas, air, oil, brine, etc. The reading instru- ments, indicator, recorder and integrator, are remote read- ing and can be supplied singly or in any combination desired. Integration is continuous, an exclusive Republic feature.	draft, rate of flow, rate of fuel feed, speed of rotation, liquid level, etc. For proportioning two pressures or flows. Regulators may be either air or oil operated. Flexibility in design and construction allows the regulator to perform any type of control action. Setting may be
PNEUMATIC TRANSMITTERS. For converting process variables such as flow, liquid level, pressure, or liquid density into air pressures which vary proportionally with the process variables. These air pressures can be used as a measuring impulse for the actuation of an automatic controller or a direct reading recorder.	remote or manual. AUXILIARY RELAYS. Multiplying, dividing, adding, stopped and maximum and minimum setting, ratio, ratio computing, sequential, splitter, squaring, square root extracting, and position indicating.
${\bf CO_2}$ METERS. Provide a continuous record of percent ${\bf CO_2}$ in flue gas measured by the Orsat method. Furnished with either mechanical or electrically actuated remote reading indicator and recorder.	COMBUSTION CONTROLS. A centralized, automatic system for controlling steam pressure, combustion, furnace pressure, excess pressure, boiler level, etc. Automatically regulates the fuel and air input to a boiler in measured proportions and in a fixed ratio for the entire load range. Adaptable to multi-fuel fring.
DRAFT INSTRUMENTS. Indicating or recording types in single or multiple units. Furnished in all standard ranges of draft and pressure.	DESUPERHEATERS. Atomizing type desuperheater uses a small quantity of high pressure steam to vaporize an automatically controlled amount of water in reducing steam
THERMOMETERS. A long distance, gas filled thermometer with either single or multiple pen recorder.	temperature to the desired degree.
LIQUID LEVEL INSTRUMENTS. Remote reading indi- cators and recorders. Also provided with various types of slarm devices.	VALVES — REGULATING AND PRESSURE REDUCING. Designed and built for all practicable ranges of pressures with either flanged or welded ends. Special body design sharply reduces erosion and noise. Cylinder operated
MULTI-POINT INDICATORS. Will indicate, on separate vertical scales from two to sixteen units of draft, pressure, flow, temperature, CO_b , etc., in any combination desired.	valves available in sizes from 3 in to 24 in. Hand operated valves in sizes from 1 in to 8 in. Lever operate valves in sizes up to 16 in. Republic valves are built in accordance with A.S.A. Standards for all pressures up to
MULTIPLE RECORDERS. Strip Chart Type will record from three to six separate records of flow, temperature, CO,, pressure, etc., in any combination desired. Round Chart Type can have up to 4 pens.	2500 psi. Diaphragm operated valves are available for pressures from 125 to 1500 psi and from 3 in. to 10 in. in size. Special purpose alloy steel butterfly valves in sizes 4 in. to 24 in. are also available.

Data Books are available on any of the above equipment

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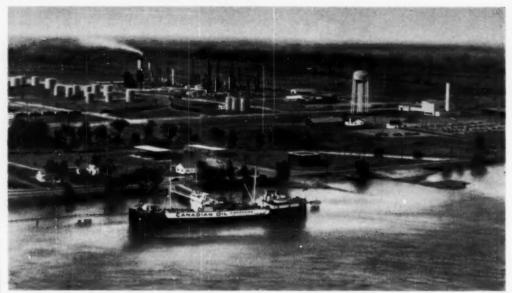
Engineering data on stainless steel tubing... prepared by engineers for engineers... pours out of Babcock & Wilcox headquarters in an endless stream of technical literature and other communications, to keep designers, stainless fabricators and process engineers wellinformed about latest stainless tubing developments and applications, and to provide an interchange of field experience among stainless tube users.

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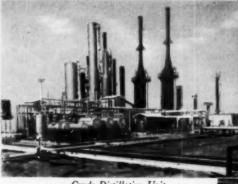
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20,000 barrels per day of Alberta Crude oil are processed in the units of Canadian Oil Refineries' Sarnia, Ontario, plant on the St. Clair River

HIGH OCTANE FOR Canada

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Whether you want to solve a knotty instrumentation problem, reduce operating costs, or improve performance, write and give details. Annin engineers will be glad to make a recommendation. Annin General Catalog 1500B gives the full story. Write for it today.

Now... <u>closer</u> temperature approaches in heat exchange



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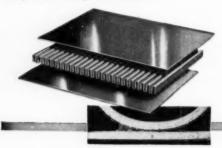
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Trane Brazed Aluminum can handle heat transfer between three, four, five or more streams simultaneously—liquid to liquid, liquid to gas, or gas to gas. Temperatures from 500° F. to -300° F. Tested at pressures up to 1000 Psig.

Want more information? Contact your nearest TRANE sales office, or write The TRANE Company, LaCrosse, Wis.



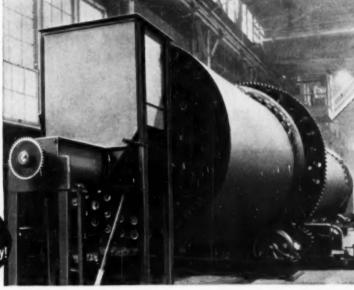
WHAT IS BRAZED ALUMINUM? A stack of flat plates and corrugated fins in layers, all brazed in perfect bond. Strong, light, compact and completely flexible. Illustration below shows strong fillet formed between fin and plate.

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Louisville Dryers are safe, automatic and economical. They require a minimum of labor, supervision and maintenance . . . and are carefully built for years of dependable service.

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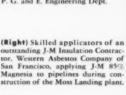
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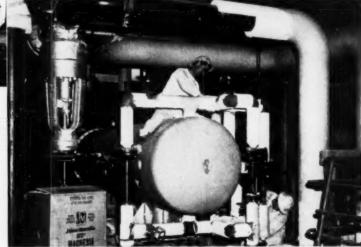
In Canada: Canadian Locomotive Company, Ltd., Kingston, Ontario

At the new Moss Landing generating plant



(Top) Moss Landing, California steam plant of the Pacific Gas and Electric Company, designed by Stone and Webster Engineering Corporation, under the supervision of the P. G. and E. Engineering Dept.





P. G. and E. INSULATES WITH SUPEREX-85% MAGNESIA TO LOWER POWER PRODUCTION COSTS

When Pacific Gas and Electric Company invested \$80,000,000 in its new 771,000-horsepower electric generating giant at Moss Landing, California...the insulation, like all other materials, had to meet rigid specifications. For this important project, Johns-Manuille Superex-85% Magnesia double-layer insulation was used on superbeated steam pipes.

Superex Combination Insulation consists of Superex®, a J-M insulation for temperatures to 1900F, and J-M 85% Magnesia. It was installed at the Moss Landing plant for maximum thermal efficiency and long trouble-free service. This double-layer construction, proved in over a quarter-century of outstanding on-the-job performance, utilizes the higher heat resistance of Superex next to the hot surface—the greater insulation value of J-M 85% Magnesia for the outer layer. It eliminates through joints, protects the jacket against scorching and

is unharmed by expansion encountered in pipes carrying superheated steam.

J.M 85% Magnesia is the leading insulation for temperatures to 600F. It will not distort regardless of its length of service. It fits snug, stays tight. Heat savings, therefore, remain constant for the life of the equipment on which it is applied.

Whatever the insulation—it must be properly engineered and installed to pay maximum dividends. That's why Johns-Manville offers industry the services of experienced J-M Insulation Engineers and J-M Insulation Contractors. These men stand ready to combine their talents and give you an insulation job that will more than pay off your initial investment with maximum fuel savings.

For further information, write Johns-Manville, Box 60, New York 16, N. Y. In Canada, 199 Bay Street, Toronto I, Ontario.



Double-Layer Superex-85% Magnesia Insulation was used on superheated piping at the P. G. and E. Moss Landing plant.

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When making an installation of a Dowtherm heated process system in your plant, it is essential their all heating equipment and interconnecting piping, as well as the Dowtherm variouszer, be properly designed and furnishes by a manufacturer with sufficient background in this type of work to know the special problems immoved. In 1932 fraster Wheeler Corporation, builders of heat exchangers and direct fixed boilers and heaters for the past fixed boilers, and heaters for the past 50 years, was the first manufacturer to design, engineer, and construct a complete Dowtherm heated processystem. Since that time, foster Wheeler has installed more than 300 vapor generators and—in most cases—has supplied and engineered the entire systems. Some of these installations include Dowtherm raportizers with co-pacities up to 35,000,000 bhu.

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SERIES 310A
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FEATURING lower cost per unit area of heat transfer surface,
National Carbon's new Series 310A "Karbate" Shell-and-Tube
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many years' experience in the application of impervious graphite
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Another new model, Series 90A, replaces the previous Series 70A to provide increased capacity and several new and improved features of construction.

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NO OTHER MATERIAL COMBINES ALL THESE PROPERTIES

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The First Hundred Years

Last month in the city of Chicago the engineers of this nation, and of others, gathered for two solid weeks of oratory. The occasion was the recognition of the one-hundredth anniversary of the founding of the American Society of Civil Engineers, the celebration of an event which, while not the beginning of engineering on this continent, was the first stirrings of one class of men toward the formalizing of an infant profession . . . How well the idea succeeded can be judged by the fact that the civil engineers were joined in devotion to their particular calling by some sixty professional societies representing a membership of 330,000. More than 290 separate technical sessions were held during the Centennial of Engineering and 1,000 papers were read on every conceivable topic, by every conceivable type of engineer.

Before this gathering of the clans, engineering may have been assumed to consist only of many and varied specialties. In a sense this is true, and while the specialties and specialists do exist, the Centennial forcefully brought home evidence that engineering is a single profession, and the unparalleled developments of the past century are not the particular developments of one group. The praise and the credit go to a profession, to a way of thinking, and to accomplishments that have completely altered man's way of life . . . if not his thinking. For truly this has been a century of engineering progress, not only in America, by Americans, but also the world over, wrought by kindred minds in kindred callings. And many were the representatives from other nations who joined in the observance.

The divisiveness of engineering—abetted by separate meetings and organizations—was minimized by the Centennial program. Engineering accomplishment was a whole, a unit; no one group could claim it for its own. Man's struggle against nature, against want, against ignorance, and superstition, against the slow tenacious grip of complacency was, in a quiet, unassuming way, dramatized. And the engineers applied the engineering tool of measurement for the dramatization. Statistics of man-hours, of horsepower, of tonnage, percentums of improvement, concentrations of energy, kilowatts, and all the varied word pictures of the engineering mind, rolled out and over the attentive audiences. Engineering may sometimes doubt its qualifications as a profession-but none could doubt that it is a way of thinking. Stamped out as graduates from educational programs of similar quality and content, the engineers in a hundred years of growth proved that varied results, products, and solutions to problems could come from similar training. As long as a man's mind was free, he would invent and produce the things that mankind needed-the varied, the good and the lasting.

Quite unconsciously the picture the engineers gave of themselves during the Centennial was of unassuming men, full of intensive yet noiseless drive, intelligence, and capability. If in the future, as in the past, others should question their worth, their purpose, their philosophy or their place in the scheme of things, the only possible answer for the "Sons of Martha" is to point to the engineering wonders of the world of today.

From such a mass of papers, talks, speeches and discussion, a news story of the meeting, reported fully and faithfully, became impossible. Rather than attempt that, the editor has abstracted from the talks some of the cogent remarks. These excerpts begin on page 40 of the News section.

We like them, and think they express the spirit and accomplishments of engineering. We have given headings to sections with the thought that this method of reporting would preserve the original and be an inducement for our readers to make this a frequent reference.

Versus

K EEP it dry and chlorine offers no trouble in handling. But, add even a trace of water and you have real corrosion problems. Problems that can cause costly damage, result in time consuming shut-downs, or constitute a serious personnel hazard. Wet chlorine must be controlled—can be controlled—easily and economically—through the proper use of the versatile TYGON family of plastic compounds.

Basically, the TYGON family consists of a series of skillfully modified and compounded vinyl resins in various physical forms: calendered or press-polished sheets; extruded tubing, channel or solid cord; molded goods; and coatings. Each form is especially suited to a particular application. Each has its us restrictions. However, all exhibit unusual general chemical resistance and desirable physical properties. All display outstanding resistance to chlorine under a wide range of conditions.

As a calendered or planished sheet, TYGON is generally used as a material of construction. In this form, it is resistant to all concentrations of chlorine at temperatures as high as 165°-175° F. When subject only to chlorine fumes, service temperatures can be raised to 290° F. Prolonged exposure to mixtures of chlorine and other chemicals, particularly solvents, is not advised without approval of U. S. Stoneware engineers.

Major use of TYGON sheets is in the lining or covering of tanks, vats, drums, hoppers, bins, blowers, impellers, fume hood and fume ducts. Considerable quantities are also die-cut into gaskets, washers and diaphragms for use as positive, durable seals, or separators, in all types of process equipment.

As extruded tubing, cord, or channel, TYGON resists chlorine in all concentrations within temperatures up to 200° F. Lengthy service with mixtures of chlorine and solvents is not recommended without qualified advice.

In extruded form, TYGON's main use is as a medium of transmission. TYGON Tubing has assumed a prominent position in both the laboratory and the plant. Its glass-like clarity, mirror-smooth surfaces, full flexibility, light weight, high strength, and long life make TYGON ideal for the smallest laboratory use or the toughest plant piping job. In the larger sizes, up to 2" ID, TYGON Tub-

ing has proved its worth in such uses as conveying chlorine from electrolytic cells to collecting heads, as permanent or temporary lines between pressure cylinders and mixing tanks, as inlet and outlet ports on pumps and filters, as syphon hoses, as line desurgers, and as flexible connections. For use at constant pressures of 40-250 psi, and at elevated temperatures, braided jacket reinforcement is available and suggested.

As molded goods, TYGON has a wide scope of application and, in general, exhibits the same resistance to chlorine as the extruded form. Specific pressure and temperature limits will depend on the size and design of the piece, but usually are greater than those for the other forms.

Typical uses of molded TYGON include gaskets, grommets, washers, stoppers, closures, handles, bumpers and special fittings. Where desired, molded TYGON can be reinforced with glass fibers for added strength. As a coating, TYGON takes the forms of a solvent type paint and a plastisol (TYGO-FLEX). Both forms are resistant to the fumes and spillage of chlorine and its solutions in any concentration and at temperatures up to 200° F. for the paint and 250° F. for the plastisol. Naturally, care in application is important and special consideration should

be given to the limits of a thin film.

When used as a paint, TYGON affords excellent protection to all types of equipment, to structural steel, to walls, and to ceilings. For mild environments, a primer and no less than two finish coats should be used. For severe exposures, a minimum of five coats over the primer is advised.

For a heavier duty coating, TYGOFLEX can be applied by spraying on hot metal and, then, fusing with heat. TYGOFLEX is also used to cast or "slush" mold flexible parts and fittings and to cover intricate shapes by dipping.

In any of its forms, TYGON provides low cost protection and a high degree of safety in the handling of chlorine and many other chemicals including acids, alkalies, oils, and greases. The different forms available and the range of mechanical, physical, and chemical properties they exhibit, permit the proper use of TYGON in many applications and under a wide variety of conditions.



In addition to TYGON in its various forms, we also manufacture a number of other materials capable of handling chlorine in any concentration and under all types of operating conditions. These products include chemical stoneware and porcelain, acid proof brick and cements, and other organic linings and coatings.

Why don't you submit your corrosion problem, today? There's no obligation and we'll be pleased to be of assistance. So write, now?

THE UNITED STATES STONEWARE CO., Akron 9, Ohio

ENGINEERS, MANUFACTURERS, ERECTORS OF CORROSION-RESISTANT EQUIPMENT SINCE 1865

OPPORTUNITY FOR CHEMICAL ENGINEERS

IN CHEMICAL MARKETING

TWENTY-EIGHT years ago when I made my first contacts with the chemical industry, salesmanship was the prime requisite. In fact, technically trained men were usually considered temperamentally unfitted for sales work, and I know that my superiors in the old Kalbfleisch Corp. had grave misgivings about turning me loose as a salesman. However, it was becoming apparent that the introduction of new chemicals to industry could not be handled adequately by "pure salesmanship" alone. Customers were thinking more about cost per unit of their product than price per pound of ours and, in addition, were becoming allergic to trying out everything new in the hope of finding some solution to their problems. In other words, they had to be shown.

There is no intention to depreciate the efforts of the pioneers in chemical selling. They did a magnificent job and many of them became technically expert. Nevertheless, the growth and increasing complexity of the business necessitated technically trained chemical salesmen, men thoroughly familiar not only with their own products, but also with their customers' manufacturing methods, trade customs, and products. Furthermore, these chemical salesmen required the advice of other technical men, spe-

cialists in some phase of the intricate business of chemical marketing.

Modern industry, therefore, in addition to the traditional jobs in production, design, or pilot plant, offers opportunities for chemical engineers in salesfield service, application research laboratories, application laboratories, packaging, market research, new product development, advertising, technical sales literature, and the patent department. This list may not fit all organizations, In some, two or more functions may be handled by the same group; in others there are further subdivisions. In any event, all are necessary and have one requisite in common-technically trained staffs conversant with their employers' products and their customers' practices.

The application research laboratories are, in this author's opinion, the best place in which to train men for almost any niche in the categories which are enumerated above. These laboratories are concerned with the problem of turning fundamental research into profit. "What is it good for," and "How is it used," are the questions asked about a new material. The evaluation must be made by experts—not amateurs—and it is in these laboratories that the knowledge of both the chemical producers' problems and the consumers' techniques and needs is available. Since the

answer to "How is it best used," usually requires knowledge of both chemistry and engineering, the chemical engineer is obviously right in his element, and usually proves the best selectee for further training.

It is always simplest to hire men who are already specialists either through training in some school or through actual experience in some specific industry following graouation from college. Such men readily fit into application research groups. Here abilities can be readily evaluated and temperaments studied so that each man may eventually be assigned to a job he can handle competently.

Men with no specific training or inclination present a more difficult problem. Such men are usually interviewed by several group leaders, and, as a rule, the applicants find some field of particular interest. Those who are uncertain may prefer assignment to the analytical division or the pilot plant, from which vantage points they can make more leisurely investigations of the relative merits of several consumer industries. When finally transferred to the application laboratory of his choice the trainee must, of course, be given opportunity to gain first-hand knowledge of the customers' business by acting as an assistant to more experienced laboratory or field service men in the demonstration of new products or on troubleshooting expeditions.

Assuming then that an employee now has the following essential qualifications: (1) technical education; (2) a thorough knowledge of his employer's products, processes, and business methods; (3) reasonable familiarity with some consuming industry's manufacturing methods and problems, and (4) ability to get along with others, he may now choose one of several roads to follow depending on his own inclination and temperament. Extroverts will probably be best suited to sales, field service, new product development, or advertis-



W. H. Harding

William H. Harding, assistant to the president, National Gypsum Co., Buffalo, N. Y., was, early in his career, associated with Parker Young Co., Lincoln, N. H., and with the Kalbfleisch Corp., in the Eastern states. After the merger of Kalbfleisch with American Cyanamid, he served Cyanamid from 1929-1951 in production, plant design and construction, field service, sales, process development, research, etc., and later as assistant director, technical service and development division. In 1942, he was appointed director of the latter and remained in that capacity through 1951. He studied chemical engineering at Brooklyn Polytechnic Institute, and received a B.S. in chemical engineering from the Massachusetts Institute of Technology. Mr. Harding was one of the founders of C.C.D.A.

ing and publicity. A man who likes change and the stimulus of new and diverse problems will find field service, the introduction of new products, new uses of old products, and trouble-shooting right up his alley. Experience in this role is excellent training for sales.

Packaging, new product development, and advertising also require men who prefer varied personal contacts and who are mentally agile. The more introverted person may prefer to stay in application research, or should he be a man who does best enlarging on the ideas of others, he will find the application laboratories, which are usually concerned with the variation and expan-

sion of demonstrated uses of in-thebarrel materials, a congenial milieu.

Market research and the patent department also offer opportunities for such men. It must be noted, however, that the latter also requires further formal education, which in many localities can be obtained at night schools.

Actually, the field of patents is only indirectly connected with sales or marketing since patents are primarily just protective devices. However, it still remains true that the patent field is a desirable place for the entrance of the chemical engineer. There are few fields where a man with a rich chemical engineering background, knowledge, imagination, and ability to think can

help a company as much as in the field of patents. As an outstanding technical adviser to the patent department, he could do a world of good, and such men are in great demand.

In any event, diverse as these jobs are, all are part of modern chemical marketing and all require the same basic training. I feel that the recent graduates in chemical engineering who presumably have the first requirements, namely, the formal schooling and a workable knowledge of products, processes and business ways and methods are indeed fortunate to find so varied a selection of worth-while and, it is hoped, remunerative jobs.

English:









A Chemical Engineering Tool

JOHN A. FIELD

N EVER in the history of industry has there been a time when the technically trained man has had the opportunity to assume leadership both in business and in community life as he has today. Responsibilities are falling increasingly on the shoulders of the technical man, not only in the physical sciences but also in other walks of life. This is, of course, particularly true of the chemical industry, which has grown tremendously during our own lifetime. Educationally, this fact has been recognized by ever-increasing specialization along technical lines. A few years ago

a man was an expert chemist or chemical engineer after a minimum of college training and a year or so in a plant. The Bachelor of Science was a rare character and the Bachelor of Chemical Engineering unknown. Today, the Doctor of Philosophy in fields of chemistry and physics and the Master or Doctor of Chemical Engineering are as numerous as the bachelor once was.

Unfortunately, with increasing specialization along technical lines, a tendency has been growing on the part of the educational institutions and of those persons being educated to underemphasize the basic values of nontechnical studies. It is becoming increasingly difficult to find men who are proficient in their chosen technical sphere and at the same time are well equipped to assume broader responsibilities in the field of personnel management, managerial activities and in the many phases of human activity not directly concerned with technical endeavor. And yet it is upon such men that industry must depend for its leaders and executives in the years to come.

It is a sad situation, indeed, to come upon a man who has good ideas but who is incapable of transmitting those ideas to his fellowmen clearly and convincingly. This is true not only of the spoken word but also of the written word. The man who can "sell" his ideas and himself, too, to his management will move along faster than the man who cannot. I do not mean to imply that a man with a "gift of gab" will be a better chemical engineer than a man with a gift for mechanics. I do mean to imply that if two men of equal ability, from a strictly engineering standpoint, are competing for executive responsibilities in an industrial enterprise, the man who can more clearly and effectively set forth his ideas and his reasons for following a given course will surely progress faster.

This writer accepts unequivocally the thesis that no matter how good a product is, it must be sold. No matter how good an engineer is, if his light is hidden, he will not realize his maximum potential. Utilizing technical abilities to their fullest and obtaining the maximum return for the investment made in your education may depend to a large extent on the job you do in selling yourself. It behooves every man to do his best to see that he does not become a "discontinued item" because his ability is not properly or attractively displayed. A good impression made by reason of personality traits, orderliness of dress and speech, and the ability to express thoughts clearly, can go a long way toward opening the doors of industry to welcome and turn to good account technical training and talents. This factor of salesmanship in selling oneself must not be overlooked by the man who is ambitious to succeed.

One of the foundations of a well-developed personality is the ability to speak and write well. You may be thinking to yourself: "What good is all this going to do me? I'm an engineer and what I need is a good foundation in mathematics and thermodynamics, not a course in English!" You are only half right if you think so, for you are overlooking the importance of being able to

communicate to those around you quickly and effectively. Did you ever stop to think that nearly all business is founded upon communications? The record of the growth of industry from the earliest times-from the "one voice" sales presentation of the itinerant peddler or huckster calling out his wares to today's highly complicated business mechanisms -is a history, step by step, of expanding means of communication. Imagine the confusion which would result if you as chemical engineers had only the vocal grunts of the stone age to communicate a theory for determining tray efficiencies in a bubble-cap distillation column. Or suppose our written language consisted of crude picture characters on papyrus, and with these pictures you were attempting to write a textbook on calculating the strength of materials. This is, of course, a ridiculous comparison, but it serves to illustrate the point that unless communications can be made swiftly and effectively, all industry will slow to a virtual standstill.

Only a few years ago the material needs of a community were supplied by small, "one cylinder" businesses. Messages were transmitted by word of mouth to customers, to workers and to suppliers. Communication by telegraph and then by telephone started rapid advances in communication techniques and in the magnitude of industrial enterprises; the old neighbor-to-neighbor relationship gave way to new forms. Personal contact has been replaced by letters, reports, technical manuals, advertising and sales literature, financial reports, reports to stockholders and other similar devices. All these tools make it possible for the corporation to carry on its business efficiently. Some of these same tools can aid the individual in selling himself or his ideas to management or to executives with whom he may have no other contact and with whom his first contact is almost certain to be in written form. As aptly said: "He who can explain himself may command what he wants; he who cannot is left to the poverty of his

own resources, for men do what we desire only when persuaded. The persuasive and explanatory tongue or typewriter is, therefore, among the prime assets which an individual must have to attain any real success." (D. E. Beebe, Alexander Hamilton Inst.)

Of all the forms of written business communications, the letter and the technical report are the most important to chemical engineers. The letter is the more important of the two since it is used much more widely and in many cases actually takes the place of the technical report. For example, an engineer may have an idea which will improve efficiencies in an operating unit. He will have complete technical data to prove his point and will assemble the whole into a report. But the information which is actually transmitted to a superior responsible for making the decisions will usually be in the form of a letter. This letter will be a brief summary of the report giving the salient facts logically, concisely and clearly to convince the superior that the proposed course of action should be followed. It is essential that this letter present the ideas proposed and the conclusions drawn in the most efficient and decisive way possible to sell the program suggested. Similarly, the detailed report must also satisfy these criteria insofar as possible. In each of these cases the letter and the report are the personal emissaries of the writer and in his absence plead his case before the bar of judgment of his superiors. If the report or letter makes a good impression, the name of the author will be fixed in the mind of his superior. If the report or letter is badly written, a poor impression will be made which may require much effort

It should be emphasized here that the ability to use English fluently and to speak or write clearly and forcefully can affect you now and in your later life in industry. A letter, report or any other written material for that matter is the personal representative of the writer. Actually, it is even more than that, since it is the writer himself, to the person receiving the letter. The whole personality of the writer is contained in its

When would a letter be likely to affect one's life to any appreciable extent? First and foremost, consider the letter of application for employment. Most men at least once in their lives are confronted by the problem of marketing their services, and the letter provides an important if not the most important medium through which an individual can broadcast his qualifications. Even though you may obtain employment offers now without having to seek them, there may



I. A. Field

John Albert Field, a native of Bayside, Long Island, graducted with honors from Yale University in 1935 with a B.A. degree in chemistry. He spent a year at Oxford University on a Henry Fellowship and joined Carbide and Carbon Chemicals in 1936 as a unit foreman in the production of miscellaneous chemicals. From 1939 to 1940 he engaged in sales research at Mellon Institute in Pittsburgh and came to the headquarters of the company in New York in 1941. During the war Mr. Field was a department head in the production of butadiene from alcohol at the Institute, West Va., plant. He later became manager of production control section, Office of Rubber Reserve, of the Reconstruction Finance Corp. After the war he rejoined Carbide and is now assistant manager of the fine chemicals division.

be a time when you will wish to change jobs because the road to advancement is blocked in your present position. Then the letter which you write will be of great importance and indeed may be the open-sesame you need. Application letters are definitely sales letter. In general, the letter which is most effective is the one in which an applicant carefully matches his abilities with the requirements of his prospective employer and in which his case is presented in a clear, forceful and interesting manner. The decision on the part of the employer to interview the applicant will rest entirely on the impression of the letter, so its importance with respect to the job in question can hardly be overestimated.

As stated previously a letter may influence your whole life. I recall an instance where a chemical engineer who was acting as a technical salesman for our products wrote a letter to the editor of a technical weekly. Several executives of the company read the letter in the periodical, found it amusing, clear, well presented. It so happened that they were at that time considering men for an appointment to a new job. The man had not been considered for the position, but as a result of the single letter was interviewed and finally got the job, a substantial promotion which had a profound effect on the course of his life. Another chemical engineer whom I know worked in a production job for a corporation supplying chemicals. He was recognized for his ability to write a smooth and readable report. In a humorous moment he collaborated on a burlesque of the company advertising which by virtue of its wit and cleverness circulated far beyond his anticipation. As a direct result of this activity, the man is now attaining executive stature in the technical service of that company.

Many chemical engineers may be considering technical sales and service for careers. If so, they will be called upon to write many letters to their customers. In such cases the letter takes on a double importance since it represents not only the writer but the company itself. As a matter of fact, letters rank first among business communications by a wide margin. As high as 85 or 90% of a company's business may be transacted by letter, yet strangely enough, improving correspondence may be one of the last things a company considers. One single letter may in one minute destroy months or years of patient effort which have gone into the building of good customer relationships. A business-destroying letter may be of more importance than many business-building letters. An unfortunate phrase, or the wrong interpretation of a word by the recipient of the letter can be disastrous. The writer is not there to correct a wrong impression or to smile ingratiatingly, and the letter must stand alone.

Some brief observations on how letters should be written can be interpolated here. The English language is a tricky one, and in no case does its trickiness show up as often as in the written word. This is due to two reasons. First, and most important, the point of view of the reader is seldom the same as that of the writer. The second reason is that words may have many shades of meaning and by virtue of context may actually convey meanings of an entirely different sort from what had been intended by the writer. We are all familiar with the misplaced phrase, such as "For Sale, a piano by a lady with carved legs.

This is just a humorous example illustrating an important feature of a letter. To be successful in its purpose, it must be written from the point of view of the reader and not the writer. That is rule number one. Edgar Lustgarten in his book "Verdict in Dispute" says much the same thing when he states:

Words exist to communicate a meaning. But the meaning inferred by the listener or the reader is not always that intended by the speaker or the writer. There are primary and secondary senses; there are overtones and undertones that are idiosyncratic; there is a hyperbole and satire; there is untrammelled fantasy and deliberate makebelieve. . . , It is only by reference to the character of their author and to the circumstances in which they were employed that one can hope to extract the true significance of words. They must be related, not only to the dictionary, but to life.

The basic purpose of a letter is to communicate facts or ideas. There is no other reason for writing a letter. Therefore, in writing a letter the fact or idea should be presented in the shortest possible space compatible with clarity and creating the desired impression. Letter writing is an art. It may require some native talent, but in the main, skill in performance results from study and practice. One would not expect to succeed in law, medicine or chemical engineering if he does not have a thorough knowledge of these subjects plus the advantage of experience and observation. Similarly one cannot expect to express himself effectively through the various media of business communications if he has not given time and effort to developing his ability to write or speak well. Here, then, are several major points to consider:

- 1. Make your letter fit your reader.
- 2. State the facts briefly and clearly.
- Express yourself courteously and politely.
- Be certain that your sentences are grammatically accurate.
- 5. Present facts or ideas in orderly fashion.



Make your letter fit your reader.

Adherence to basic rules of English is probably second nature to most of us. Therefore, most of the inaccuracies which occur from time to time in letters are primarily due to carelessness or hurried writing. Word choice is a relatively simple problem and we should not be ashamed to use a dictionary to secure the right word with the exact meaning desired. It is important, too, that we use definite words rather than vague words to give our writing crispness and purposefulness. Orderly presentation of ideas depends on organizing your thoughts before you write; then they can be presented in correct sequence with logical conclusions. Some people can do this mentally, others jot down an outline and still others may first write an important letter in rough form with the deliberate intent to revise. Here again, experience and practice are important factors in developing the ability to write in a well-organized manner.

Some precautions to be observed in writing letters are:

Don't overlap two separate ideas in the same sentence. It tends to be confusing. Use paragraphs intelligently. One major thought to a paragraph is a good rule of thumb.

Avoid use of long words. Long words tend to be confusing and often increase the difficulty of reading. There are exceptions to this rule, such as chemical or equipment names and technical terminology.

Avoid use of long sentences. Use of short sentences makes for definiteness in thought processes.

Avoid use of slang. Slang should be limited to terms familiar to a trade or occupation with which the reader will be familiar and which are in everyday use in his business.

Avoid use of adverbs. Such words as "extremely," "very," are usually unnecessary.

Avoid use of overworked phrases. "Attached please find," "contents carefully noted," "in replying we wish to state that" and others. These are overworked, and overworded statements of obvious facts.

Avoid use of phrases which imply that a customer is wrong, dishonest or ignorant.

Avoid strong modifiers. Words such as "unjust," "unreasonable," or "inexcusably" evoke wrong reactions.

Avoid the pompous attitude. This is characterized by such phrases as: "in accordance with our policy."

Avoid the negative approach. Don't back into a situation. Keep your letter positive and straightforward.

Many of the rules and suggestions made so far are not limited to the composition of letters but are basic rules which can be applied to all writing including the preparation of a report. Obviously a report cannot be written in the same way as a letter. It must be an impersonal and accurate presentation of a subject based upon investigation. The

information contained in a report is a record and analysis of conditions, activities and data, past and present, from which a statement of conclusions and a recommendation for future action have been made. The purpose of a report is to supply information to an executive or superior to permit him to make a decision which will play a part in the operation of a business. A report may carry conviction, to bring the reader around to a certain point of view and to persuade him to adopt the recommended course of action. A report of a sales call may present the particular competitive situation involved, the general market possibilities, a summary of products in which a prospective customer is interested or a suggested procedure for developing sales. Reports by members of the research staff present new scientific data-engineering reports present economic and structural data without which the construction of chemical plants would be an impossibility. In other words, the report is of the utmost importance to industry. To individuals the report is also important since it is the best means of bringing their ability to the attention of superiors and the managerial group in a company. Everyone who seeks to attain administrative proficiency must develop the ability to express himself well in report form.

A few suggestions to improve report writing, implemented by those points made previously in connection with letter writing, are:

- The report should be easy to read.
 It should consist of clear, concise sentences and simple, meaningful words.
- 2. Conclusions and recommendations must be presented briefly, logically. In such a form the report can be absorbed by the reader with a minimum of effort and a maximum of comprehension. Conclusions which involve a degree of doubt should be accompanied by such an expression as: Results of the study indicate.
- 3. Supporting arguments should be expressed clearly and concisely. Too much elaboration of detail or too voluminous an explanation may reduce the effectiveness of the report to such an extent that no action on it is ever taken.
- 4. The report should answer all questions. Most of the questions the reader is likely to ask can be answered in the form of supporting data and tables ap-



Don't back into a situation.

pended to the summary report. This prevents a multitude of data and calculations from distracting the attention of the reader from the points to be emphasized.

- A report should be devoid of vague and meaningless expressions.
- 6. Do not waste time and energy in writing "do nothing" words and phrases.
- 7. Submit a report for criticism to another person before final publication. This tends to eliminate errors which result from idiosyncrasies of the writer. It also affords a means of double-checking for errors which the writer might overlook because of his proximity to the subject. Comment from someone with a different perspective is always helpful.

8. A report should be clearly typed.

In conclusion, this writer would emphasize the fact that the same basic rules of good English apply to speech as well as to writing. The man who can express himself fluently and convincingly can secure the enthusiastic cooperation of those around him and can sell himself and his ideas to his superiors and fellowworkers. In addition, more and more as you grow in your industrial careers you will be called upon to represent your company in public speeches or in your community life. Here again the ability to talk easily, logically and fluently will give a man a great advantage over a competitor who is unable to do so.

Appendix

The following list of books should prove helpful to the chemical engineer in his study of the successful use of one important tool—the English language.

- "Writing the Technical Report"—Nelson, J. Raleigh, McGraw-Hill Book Co., Inc., New York (1947).
- "Improving Your Vocabulary"—Stratton, Clarence, Whittlesey House, McGraw-Hill Book Co., Inc. (1947).
- "Speak Well—and Win!"—Sandford, William P., Whittlesey House, Mc-Graw-Hill Book Co., Inc. (1944).
- "Public Speaking and Influencing Men in Business"—Carnegie, Dale, Association Press (1926).
- "Public Speaking—As Listeners Like It?"—Borden, Richard C., University College, New York University, Harper and Brothers, New York (1935).
- "The Way to Write"—Flesch, Rudolf, and Lass, A. H., Harper and Brothers (1947).
- "The Art of Useful Writing"—Pitkin, Walter B., Whittlesey House, Mc-Graw-Hill Book Co., Inc. (1940).
- "The Art of Plain Talk"—Flesch, Rudolf, Harper and Brothers (1946).
- "Clear Writing for Easy Reading"— Shidle, Norman G., McGraw-Hill Book Co., Inc. (1951).
- "Business Letters and Communications"—Beebe, Dwight E., Alexander Hamilton Institute, New York (1949).

(Presented at Columbia University, New York.)

PRODUCTION OF METHANE FROM COAL

An Economic Study

L. W. ALBERTS, J. S. BARDIN, D. W. BEERY, H. R. JONES, and E. J. VIDT

Blaw-Knox Construction Company*, Pittsburgh, Pennsylvania

A RECENT editorial (2) states that it is reasonable to expect that ratural gas reserves, within five to ten years, will all be dedicated to existing interstate pipe lines and to large-volume use at the point of production. This means that sections of the country not already served by interstate pipe lines will be unable to obtain gas and that existing customers will be unable to get additional amounts.

Industry is already feeling the pinch where it depends upon "interruptable" gas. Such interruptions during periods of high domestic demand are costly in increased maintenance, investment in stand-by equipment, and high-cost standby fuel.

Chemical Plants Division.

The normal result of increased demand and short supply is increased prices. Industry faced with higher fuel costs through stand-by equipment can pay more for a noninterruptable supply of fuel. The gas-hungry domestic public would be willing to pay a reasonable increase in present fuel costs for the convenience of gaseous fuels. How high the cost of natural gas may go is a matter of conjecture today but rise it must.

Production of gaseous fuels from solid fuels at locations remote from a supply of natural gas may be an answer to a portion of this demand. It is the purpose of this paper to develop the economics of manufacturing methane from coal by the hydrogenation of carbon monoxide. The methane will be produced in quantities suitable for trans-

mission in cross-country pipe lines, that is 100 million std.cu.ft./day or more.

The process shown in Figure 1 begins with the preparation of synthesis gas Ly reaction of a noncaking coal, or its equivalent, with oxygen and superheated steam in the Lurgi pressure gasifier. The gas produced is cooled and then completely desulfurized in the Rectisol initial purification step. The carbon dioxide content is simultaneously reduced. Following purification the gas is passed over a methanizing catalyst to produce a mixture of CH4, CO2 and H.O. This stream is treated by the Rectisol final purification step to remove CO2 and to dehydrate the gas. It now has a heating value of more than 900 B.t.u./cu.ft. and is ready for delivery to the pipe line. It is a satisfactory replacement for natural gas.

The plant described in this paper is designed to furnish all of its own utilities. Investment costs have been calculated for a plant producing 100 million std.cu.ft./day. These costs include engineering design, procurement, and erection of the plant, interest on the capital invested during erection, and working capital. Raw material, labor and maintenance costs have been determined. Costs of the utilities have been similarly developed.

Gasification

The synthesis gas for the process is produced in 12-it. (I.D.) Lurgi pressure gasifiers. Units of this type have been described by Hollings et al. (4) and by others (5, 9). Satisfactory operation of Lurgi generators requires that the charge be relatively noncaking. However, since the mining and processing of the coal are beyond the scope of this paper, the assumption here is that suitable material is delivered to the site of operation. In the economic study of this process the cost of fuel will be

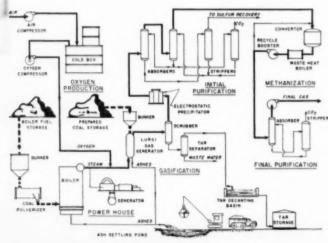


Fig. 1. Schematic flow diagram,

TABLE 1

	Rew Lurgi Ges	Gas Leaving Initial Purification	Ges Leaving Nethonization	Pipeline Oss
12	40	54.8	8.6) 10-9
00	20	27.4))
co ²	30	4.3	22-1	2.0
CH	0	10.9	63.6	86.9
C2H6 & 111.	2.	2.4	2.85	3-5
H2	_2_	1.8	2.85	3.7
	100	100.0	100-0	100.0
H ₂ S (greins/ 100 SCF)	275	0	0	0
Inorganic and organic sulfur (grains/100 SCF	12.5	10-1	(0.1	0.1
Volumes	100	73*	35.0	27.5
Heating Value (BTU/SCF)	293	401	791	915
Specific Gravity	.73	.45	.75	-57

treated as one variable.

The reactions which take place in the gas generator have been discussed in the papers just listed. The relatively high percentage of methane formed during pressure gasification is of considerable advantage in the present process. For the same amount of carbon gasified, the higher the methane yield, the lower the oxygen consumption, because methane formation is less endothermic than water gas formation. These two effects make pressure gasification attractive when preparing synthesis gas tor methanization because they both reduce operating costs. Table 1 shows the approximate composition of the raw Lurgi gas.

The gas leaving a generator is cooled with water in two spray coolers in series. The tar and most of the water vapor are condensed and separated. The condensed water contains small amounts of tar, phenols, and other materials. In preparing boiler feed water by distillation the waste heat in the water is used. The water itself is distilled and the steam produced from the distillate is recycled to the gasification

Following the spray coolers the gas passes through a tubular cooler. Remaining amounts of tar and ash in the gas stream are removed by electrostatic precipitators.

Initial Purification. Methane synthesis catalysts under present operating conditions are sensitive to sulfur. The raw Lurgi gas must be purified to remove all sulfur compounds and CO₈.

In the present case H₈S, organic sulfur compounds and CO₃ are removed by the Rectisol process, a low-temperature extraction, recently developed by the Lurgi Gesellschaît fuer Waermetechnik m.b.H. and the Gesellschaît fuer Linde's Eismachinen A.G., (Germany). It has the advantage over the ethanolamine and similar extraction processes that it will remove organic sulfur compounds as well as gum formers. This allows substitution of a single process for the multiple processes commonly in use. The Rectisol process in the present case is conducted in two absorption steps. The first step yields a waste gas enriched in H₈S, which is fed to a sulfur-recovery unit. Waste gas from the second step contains most of the CO₅.

Methanization

Synthesis of methane was disclosed by Sabatier (7) in 1896. Since then it has been extensively studied for the enrichment of town gas (3). Akers and White (1) have summarized the kinetics of the reactions when catalyzed by nickel. The catalytic production of mathane by a series of reactions, which may be represented by:

$$4CO + 8H_2 \rightarrow 3CH_4 + CO_2 + 2H_2O$$

is preferably carried out over a nickel catalyst. The reaction is exothermic, liberating about 92,000 B.t.u./lb. mole CH₄ at 300 lb./sq.in. gage and 600° F. In order to remove the heat of reaction large volumes of reacted gases are recycled. Gases leaving the catalyst are passed through a waste heat boiler to cool them. The steam generated is used in the Lurgi gas generators. In order to achieve a gas of 900 B.t.u. or more heating value it is necessary to obtain at least 95% conversion of H₂ and CO. The cost of methanization is treated as a variable in this paper.

TABLE 2.-STEAM BALANCE

			STEAM	PRODL	CED			STEAM CONSUMED								
UNIT	1400 psig. 950° F	375 eng 872° F	375 asig 715° F	375 paig 647° F	375 psig. 442° F	20 psig. 297° f	20 ps q 298° F	1400 paig. 950° F	375 esig. 672° f	375 esig. 115° f	375 paig. 647° f.	375 peig 442° f	20 mg	20 paig 256" f		
Gesification				-		-	1,300	9,230	1,119,000	0	1,300	-	7,490	9		
initial Purification	-	-	-	-	-	-	-	130,200	-	0,200	-	0.200	197,200	2,300		
Wethenizetlen	-		488,200	-	\$37,000	-	3,420	485,100	-	-			-	46		
Final Purification		-	-	-		-		21,600	-	-	-	-	-	8,340		
Final Gas Compression	-	-		-	-	-	-	96,520	-	-	-		-	-		
Austiney Foculities	-	-	-	-	-	-	6,280	6,290	-	-	-	-	-	4,290		
high Prassure Steem	1,240,000	0		-		-	-	-	-	-	126,400	-	-			
Low Pressure, Steam	-	1,119,000	-	-	-	-		~		480,000	105,200	129,000	-	-0		
Electric Pewer	-	-	-	235,000	-	122,700		357,700	-	-	-	-	-	-		
Cooling Woter	-	-	-	-	-		-	-	-	-	-	-		-		
Boilet Feed Woter	-	~	-	-	-	-	-	-	-	-	-		-	-		
Daygan Production	-	-	-	-	-	71,980	-	112,100	-		2 800		-	- 64		
Daygen Compression	-	~	~	-	-	-		79,870	-	-	-	-	-	~		
TOTAL	1,260,000	1,115,000	489.200	2 35,000	537,200	194,650	11,000	1 260 000	1,115,000	488,200	2 35,000	537,200	194,650	11,000		

Att Units ore Pounds per Hour

	POWE	R PRODU	CED	POWI	POWER CONSUMED				
UNIT	9,600 volts	8,300 volts	440 volts	2,300 volta	440 volta	HO/230 vot			
Gasification	-	-	-	-	337	-			
Initial Purification	-	395	-	8 57	21	-			
Methanization	-	-	-	279	-	-			
Final Purification	-	-	-	414	63	-			
Final Gas Compression	-	-	-	-	2	-			
Auxiliary Facilities	-	-	-	-	2,230	3,720			
High Pressure Steam	-	-	-	6,887	48	-			
Low Pressure Steam	-	-	-	~	3	-			
Electric Power	80,000	-	-	-	6	-			
Cooling Water	-	-	-	3,328	2,121	-			
Boiler Feed Water	-	-	-	895	114	-			
Oaygen Production	-	-	1,005	-	72	-			
Osygen Compression	-	-	-	-	3	-			
TOTAL	20,000	395	1,005	12,660	5,020	3,720			
GRAND TOTAL		21,400			21,400				

All Units ore Rifewatts

Final Purification. In order to obtain the maximum B.t.u. value in the gas after methanization the CO₂ is removed by the Rectisol process. The CO₂ content of the final gas is of the order of 1%. The water must be removed to prevent condensation and hydrate formation in the gas transmission line. The Rectisol process removes the CO₂ and simultaneously dehydrates the gas at no additional expense. Leaving the final purification step the gas has a heating value of more than 900 B.t.u./std.cu.ft. and is mittable for transmission has size for

mittable for transmission by pipe line.

Removal of CO₂ by scrubbing with water under pressure is usually inexpensive but the solubility of methane at 300 lb.sq.in.

age is appreciable. This, plus the cost of subsequent dehydration, makes water tashing more expensive than Rectisol.

Final Gas Compression. The gas leaving the final purification step is compressed to pipe-line pressure of 1200 lb/sq.in. gage before leaving the plant. The low cost of

utilities produced within this plant makes it desirable to do as much of the work of compression as possible before the gas leaves the plant.

Materials. The gasification process requires 90.1 lb. of fuel, 41.4 lb. of 95% oxygen, and 268 lb. of superheated steam/M cu.ft. of final pipe-line gas. The fuel consumption is based upon a hypothetical non-caking fuel having a heating value of 13,000 B.tu./tb. (26,000,000 B.tu./ton) which will not produce any tars or oils in the gasifier. The daily consumption for gasification is 4,505 tons. The feed must be sized between ½ in. and ¾ in. for maximum efficiency. It has been assumed for this paper that prepared feed stock has been delivered to storage piles adjacent to the plant. It has also been assumed that fines produced during coal-handling and preparation operations are used as boiler feed.

TABLE 4.—COOLING WATER BALANCE

UNIT		WATER I	PRODUCE	D		WATER	CONSUM	€D
APPROXIMATE TEMPERATURE	80+5	90*f	10015	11000	BOok	90°F	100° f	110*
Gasification	-	~	0 93	1.72	2 70	-	-	1.21
Initial Parification	-	18 47	1 30	23 41	30 40	12.77	-	-
Wethanisation	-	-	-	2 04	2.04	-	-	-
Final Publication	-	3 07	-	2 45	3 37	2 13	-	-
Finel Gos Compression	-	-	-	6 64	-	6 64	-	~
High Pressure Steem		-	-	-	-	-	-	0.6
Low Pressure Steem	+	-	-	-	-	-	-	0
Electric Power	-	*	-	-	-	-	-	~
Cealing Water	-	-	-	-	-	-	-	-
Monorup Water	21.00	-	-	-	-	-	-	-
Cooling Towars	36.96	-	-	-	19.25	-	-	77.7
Evaporation & Windage		-	-	-	-	-	-	172
Boiler Feed Water	-	-	-	54 17	20 54	-	33 30	
Ozygen Production	-	-	23 19	5.49	20 49	-	-	
Ovygen Compression	-	-	9.96	1.01	10.91	-	-	~
TOTALS	117.96	21 54	35.38	25.25	117.96	21 54	35.38	26.9

All Units ore Thousands of Gallons / Minute

The daily requirement of 2,070 tons of 95% oxygen must be provided at 375 lb/sq.in, gage and at the compressor discharge temperature. In addition 13,380 tons/day (1,115,000 lb/hr.) of 375 lb/sq.in. gage, 850° F. steam are consumed.

The oxygen plant consists of five 500-ton Linde-Fraenkl units. Large volumes of air required allow the use of centrifugal or axial-flow compressors. The 95% oxygen is produced at atmospheric pressure and must be compressed before entering the gas generators. Centrifugal machines are used for this service. The oxygen leaving the final stage of compression is not aftercooled as it is desirable to have it enter the gasifier at a temperature as high as possible.

as it is desirative to have their tile gashler at a temperature as high as possible.

The steam which is supplied to the gas generators is produced in part in the waste heat hoilers of the methanization unit. An additional large amount is obtained from the exhaust of the turbines driving the methanization recycle blowers. A small amount of make-up is extracted from the main turbogenerators. Superheating is done in separate coils located in the high-pressure boilers.

Utilities. The plant proposed here is self-sufficient in utilities. Steam is generated at 1400 lb./sq.in. gage and 950° F. in pulverized coal-fired boilers. These boilers generate 1.260.000 lb./hr. of steam at 87.5% thermal efficiency. This steam powers all large prime movers in the plant. All mechanical drive turbines are operated condensing except for those driving the recycle blowers of the methanization unit. These exhaust at 375 lb./sq.in. gage as described earlier. Process steam at 375 lb./sq.in. gage extracted from the main turbogenerators. This steam is used for heating.

is used for heating.

A steam balance of the plant is presented in Table 2. This shows the primary production of high pressure steam and the generation of 375 lb./sq.in. gage saturated (442° F.) steam in the methanization unit waste heat boilers. Steam is also shown as being produced from those turbines, pumps, etc., which exhaust steam above atmospheric pressure. Consumption of steam at the various design conditions is shown.

Power is generated and distributed at 9600 v. It is reduced to 2300 or 440 v., 3-phase, at the various operating units. All drivers of 100 hp. or less receive 440-v. power, larger drivers 2300 v. Electric motors are used wherever the water rate of an equivalent steam turbine would be more than 7.0 lb./hp.hr.

An electric power balance is shown in Table 3. It is noteworthy that in addition to the power generated at 9600 v. in the main turbogenerators, there is also power generated as a by-product of two of the operating units. Waste CO₂ from the initial purification unit is expanded in a turbine generating power at 2300 v. Turboexpanders of the Linde-Fraenkl units also generate power at 440 v. Consumption figures are broken down into the various voltages. All lighting facilities are included under "auxiliary facilities" at 110/220 v.

In order that the plant design may be generally applicable, it has been assumed that the supply of cooling water is limited. A circulating water system using induced-draft cooling towers has been designed. Make-up water, 22,000 gal./min., is pumped through the surface condensers of the turbogenerators. It is neutralized and deflocculated before entering the circulating water system. The system has been designed for a circulation rate of 118,000 gal./min., 73° F. wet-bulb temperature, 80° F. cold water and 30° F. temperature rise. A

TABLE 5

INVESTMENT BURNARY

A - Utilities	Labor, Natorial and Overbead	Adjusted
High Pressure Steem Low Pressure Steem Blactrie Power Cooling Natur Boiler Pawd Water Guygen Production Curyeen Compression	\$ 7,580,000 932,000 1,940,000 2,930,000 2,365,000 10,940,000 915,000	\$ 8,360,000 1,050,000 2,140,000 3,230,000 2,610,000 11,400,000 1,010,000
Utilities Subtotel	\$27,022,000	\$29,800,000
B - Process Units		
1. Gasification 2. Initial Parification 3. Methanization 4. Pinel Parification 5. Pinel Gas Compression 6. Auxiliaries	\$ 5,860,000 3,715,000 2,565,000 1,088,000 770,000 6,580,000	\$ 6,460,000 4,100,000 2,830,000 1,200,000 650,000 7,260,000
Process Subtotal	\$80,578,000	\$22,700,000
Total Communication Cost	\$47,600,000	\$52,500,000
Interest on Capital During Construction (essumed)	\$ 2,510,000	_
Working Capital (assumed)	2,390,000	-
Total Investment	\$52,500,000	#52,500,000

cooling water balance is shown in Table 4. This table shows consumption figures for II0°F, water. These refer to blowdown water which is purposely wasted to prevent salt build-up in the cooling towers. This water is used to transport ashes from the gasification unit and boilers to the ash-settling pond and is then discarded.

The make-up feed water for the highpressure boilers is produced from the available cooling water by distillation. Feed to the methanization waste heat boilers is similarly prepared from the undissociated steam condensing from the raw Lurgi gas. The distillation units use waste heat which is contained in the gases leaving the Lurgi generators. In calculating the cost of coal gasification a credit is allowed for the value of this heat as it replaces coal as a means of heating boiler feed water.

Investment Costs

Costs are based on an engineering estimate of costs which has been completed by Chemical Plants Division, Blaw-Knox Construction Co. The authors' studies of plants producing more than 100 million std.cu.ft./day have indicated that unit costs in this range are practically independent of plant size. Smaller plants have not yet been investigated

The plant described here will be operated as a public utility. It must be capable of operating at full design capacity with a 100% load factor. Adequate spare equipment has been provided

to make such operation possible. If units are shut down for preventive maintenance during warm weather months this spare equipment will allow production of about 20% additional pipe-line gas during winter months, when demand is high. Such excess capacity will reduce the annoyance of interruptions suffered by large commercial consumers. Further, since investment is not increased, the unit cost of the product will be reduced when the output is increased.

In Table 5 a summary is given of the investment in dollars for the 100 million std.cu.ft./day plant. These costs include the design and procurement of the equipment and the labor and overhead charges incurred during construction. There are unknown factors about a project of this magnitude which cannot be evaluated at this stage. For this reason the designation "auxiliaries" has been set up. Under this are included general site preparation-grading, storage tanks and loading facilities for by-products, roads, rail sidings, etc.-sulfur recovery, waste disposal, fire protection, administration buildings, warehouses, shop facilities, change rooms, etc. The separation of oxygen from the air and its compression to 375 lb./sq.in. gage have been included as utility items.

The interest charge on the capital required during the construction period has been added to these costs. Working capital has also been provided.

The investment has been broken down in Table 6 into equipment costs for the individual process and utility-producing units.

Depreciation costs have been calculated as shown in Table 7. The amortization periods used are based in part on the Bureau of Internal Revenue tables (8). On equipment peculiar to these processes obsolesence has been

TABLE 7

DEPRECIATION TABLE

THELE 6

INVESTMENT BREAKDONE

					Cupital	of Total Capital	Amortisation Time-Years	Rate of Depreciation
Plant I	Labor, Material, Overhead	Adjusted						
	Overness		3.	Tobular Busipment	\$ 3,900,000	7.43	3.2	5.92%
1. Tubular Sautpment	\$ 3,5k0,000	\$ 3,900,000	2.	Machanical Equipment		19.46	7	11-90
2. Machanical Equipment	8,800,000	9,702,000	3.	Tanko and Vessels	6,242,000	11.89	35	4.30
1. Tanks and Vessels	5,660,000	6,242,000	A.	Boilers & Duperheate	r 4,862,000	9.36	30	9.72
a. Boilers and Superhesters	4,410,000	4,862,000	5.	Low Temperature				
5. Low Temperature Equipment	5,800,000	6,400,000		Moutpeent	6,400,000	12.19	20	2.72
6. Cooling Towers	1,260,000	1,391,000	6.	Cooling Towers	1,391,000	2.65	15	4.30
7. Purbagenerators & Power Switching	1,390,000	1,533,000	7.	Turbogenerators 5				
8. Instruments	1,070,000	1,181,000		Pewer Switching	1,533,000	2.90	80	2.72
9. Piping	4,760,000	5,250,000	8.	Instruments	1,181,000	2.25	10	7.58
10. Structural - Building and			9.	Piping	5,250,000	10.00	15	4.30
General Construction	1,730,000	1,911,000	10.	Structural - Buildis	4			
11. Electrical Equipment	1,420,000	1,565,000		and General	-			
12. Insulation	1,160,000	1,281,000		Construction	1,911,000	3.64	12	2.72
13. Auxiliaries	6,600,000	7,282,000	33.	Electrical Equipment	1,565,000	2.98	1.2	5.92
			12.	Insulation	1,881,000	2.44	7	11.90
	\$47,600,000	\$52,500,000	13.	Auxiliaries	7,282,000	13.87	12.0	5.90
Interest on Capital During Construction					52,500,000	100.00		
(addisond)	2,510,000				72,700,000	200.00		
Working Capital (assumed)	2,390,000	*			lete of Inter			6.00%
					verage Rate			5.906
	\$52,500,000	\$52,500,000			Amortisation			

	GASIFICATION	INITIAL PURIFICATION	METHANIZATION	FINAL PURIFICATION	FINAL COMPRESSION	AUXILIARIES	PROCESS UNITS	TOTAL
CAPITAL COSTS								
Return on Investment	1.07	0.67	0 47	0 20	0 14	1.19	3.74	8.48
Depreciation Real Estate & Personal Property Toxes,	-97	9.5	.72	.25		1.14	4.24	0.40
Annuities, Insurence, etc.	_44		19	.00	.06	.50	1.55	3.60
TOTAL CAPITAL COSTS	2.48	1.87	1.38	0.53	0.44	2 .83	9.53	20.71
PROCESS RAW MATERIALS								
Fuel for Utilities	-	-	-	-	-		-	7.21
Fuel for Gasification	18.02	-		-	-	-	18.02	18.02
Process Steam	10.68	-	-	-	-		10.68	-
Oxygen	0.51		-	*	-	-	8.51	-
Salvent	-	0 24	-	0 09	-	-	.33	3
Catalyst	-	-	1.92	-	-	-	1.98	1.9
Water Treating Chemicals	-		_	_		_	-	.0
TOTAL PROCESS MATERIALS	37.21	0.24	1.92	0.09	-	-	39.46	27 52
UTILITIES								
Remodementolist	0.14	2.93	(3, 87)	0.22	0.54	0.20	0.06	-
Steam	(0.44)	2.00	(3.01)	0.44	0.04		(0.44)	-
Waste Heat	.03	.04	.62	04	Negl	.90	1.03	-
Electricity	.06	47	.04	05	.06	-	.68	-
Cooling Water	02	-	.99	-	-		1.01	-
Boiler Feed Woter	- 08		-99	_	_			_
TOTAL UTILITIES	(0 19)	3.34	(2.02)	0 31	0.60	1,10	2.34	-
LABOR & OVERHEAD								
Direct Operating Labor	0.66	0.09	0.14	0.07	0.05	-	0.99	1.5
Overhead & Administrative	0.40	0 06	0.09	0 04	0.01	-	.59	1 4
TOTAL LABOR & OVERHEAD	1.06	0.15	0 23	0.41	0 03	-	1.58	2.3
MAINTENANCE & REPAIR	0.71	0 45	0.31	0 13	0 05	0.79	2 44	4.7
TOTAL COSTS	41.27	6.05	1.02	1.17	1.12	4.72	55.35	55.3

Based upon fuel at \$4.00 per ton

Note: Credits ore shown in parentheses ()

considered. For this equipment amortization periods are correspondingly reduced. The rate of depreciation has been calculated on a sinking-fund basis using a 6% interest rate. The average rate of depreciation has been calculated by adding the individual products of per cent of total capital and rate of depreciation.

Cost of Producing Pipe-line Gus. A summary of production costs is presented in Table 8. In this table fuel has been assumed to cost \$4.00/ton and the methanization catalyst 1.9 cents/M std.cu.ft. of pipe-line gas. The effect of varying these costs will be treated later. Since the sale of pipe-line gas in the quantities produced in this plant will involve a public utility, it is logical to assume that an over-all return of 6% based on capital investment will be required. A depreciation cost based on the average depreciation rate of Table 7 is assessed on the basis of capital invested. An additional 2.5% cost has been added

to take care of real estate and personal property taxes, annuities, insurance, and similar items.

Maintenance and repair costs have

Maintenance and repair costs have also been determined as a percentage of the capital investment. For electric power generation, cooling water supply, oxygen production and compression, and final gas compression this has been assumed to be 2%; for all other units 4%. Ordinarily maintenance rates are low for utilities-producing units. However, these steam costs include coal- and ash-handling equipment with which greater maintenance expenses are anticipated. Similarly, higher expenses are expected with the evaporative preparation of the boiler feed water. The lower rate set for oxygen production is based upon long experience of those using plants designed by the Gesellschaft fuer Linde's Eismaschinen A. G. Oxygen and final gas compression are handled by large centrifugal or axial flow machines which require little maintenance and repair.

Unit costs of utilities are given in Table 9. These utilities are all produced within the plant and are consequently dependent upon the cost of coal. Accordingly, they are shown at two different coal costs, utilities costs at other coal costs may be found by interpolation.

Direct operating labor costs, as shown in Table 8 are an estimate based upon

TABLE 9
UTILITIES UNIT COST SUMMARY

Beillea	<u>Onis</u>	Forl 0 \$4.00/ton	Fuel @ \$8.00/ton	
Righ Pressure Steen 1500 psig, 950°F	1,000 Eta.	\$ 0.398	\$ 0,609	
Low Pressure Steam 375 paig, 850°p 375 paig, 850°P 375 paig, 642°P 375 paig, 642°P 20 paig, 29°P°P 20 paig, 258°P	1,000 lbs. 1,000 lbs. 1,000 lbs. 1,000 lbs. 1,000 lbs. 1,000 lbs.	0.395 0.372 0.361 0.324 0.316 0.313	0.607 0.569 0.553 0.496 0.487 0.480	
Riectric Power	RAMB.	0,00351	0.00427	
Cooling Water, 80°F	1,000 Oal.	0.01238	0.01297	
Boiler Feed Water	1,000 Ebs.	0,0744	0.0874	
Oxygen Production	Ton MECT	3.368 0.1415	3.803 0.1610	
Oxygen Compression	Ton MSCF	0.742	0.943	

current, large-scale American practice. Overhead and administrative expenses have been assumed as 60% of the direct labor costs. This overhead does not include social security, workmen's compensation, vacation pay, etc. These items have been included as "taxes, annuities, insurance, etc.," under capital costs.

Total Process Units is a summation of the preceding columns. It gives the cost of pipe-line gas as delivered to the pipeline at 1,200 lb./sq.in. based upon \$4.00/ton fuel and \$0.019/M std.cu.ft. for methanization catalyst when these units are supplied with utilities at the costs shown in Table 9 for \$4.00/ton fuel. The effect of changes in cost of the utilities can readily be applied to these costs to find the effect on final product cost.

Under Overall Total the cost of the entire plant is presented including the utility-producing units. In this column the effect of changes in the cost of process raw materials can be observed. All costs based on capital are increased by the investment in utility-producing units. Labor costs are likewise increased. This column shows that the principal variables in the cost of finished gas are the cost of fuel and

methanization catalyst.

Inspection of Table 8 shows that gasification represents 75% of the total cost of producing high-B.t.u. pipe-line gas. The cost of initial purification is 11% of the total, methanization is 2%, final purification 2%, final gas compression 2%, and auxiliaries are 8%. If the auxiliary costs are proportioned among the other costs, the total cost of producing the purified Lurgi gas is 93.5% of the total. The remainder of the cost is about evenly distributed between methanization, final purification, and final gas compression.

All these calculations have been based on a hypothetical fuel which produces no tars or oils on gasification. Since fuels containing no tars and oils are rarely obtained, the gasification unit is designed to handle the by-products formed. Tar storage and loading facili-

ties are furnished.

Provided that a coal has noncaking properties which allow it to be charged directly to the Lurgi gas generator, the tars and oils which will be recovered will have a greater value than the coal from which they are prepared. The increase in value must be used as a credit to reduce the cost of pipe-line gas. For example, assume that a particular noncaking coal will yield 30 gal./ton oit tars and oils having a value of 8 cents/gal. Such tars and oils can be assumed to have a heating value of 150,000 B.t.u./gal. (18,000 B.t.u./lb.). Then the heating value of the tar separated is $30 \times 150,000 = 4,500,0000$ B.t.u./ton of

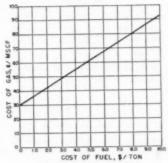


Fig. 2. Effect of fuel cost.

coal charged. Due to this loss in heating value we must charge 26,000,000/26,000,00 - 4,500,000 = 1.21 tons of coal instead of the 1.0 tons previously used as a basis of this report. This is a daily requirement of 5451 tons of process coal. The saving effected is as follows:

of the gas and on the cost of the individual utilities is linear. The rate of change depends upon the portion of the cost of the individual utility which depends upon energy.

Charge to the Lurgi gas generators must be relatively noncaking. A desirable feature of this generator is ita ability to recover tar and light oil from the charge. The value of this byproduct is greater than that of the fuel, resulting in a credit which may be used to reduce the cost of the fuel. Caking coals must be pretreated before entering the generator. This may be done by:

- 1. Low-temperature carbonization
- 2. Weathering
- 3. Oxidation

Such pretreatment is beyond the scope of this paper except as it may affect the cost of the generator charge stock.

Effect of Methanization Catalyst Costs. The cost of methanization cata-

Original cost of process coal $4505 \times \$4.00$ = \$21,804 | Process coal with tar recovery = $5451 \times \$4.00$ = \$21,804 | Recovered tar credit = $5451 \times 30 \times \$0.08$ = 13,082

Net cost with tar recovery 8,722

0.709 /days

Saving with tar recovery 9,298/day*

* This is equivalent to 929,800/100,000 = 9.30 cents M std.cu.ft. of pipe-line gas. The net cost of the pipe-line gas then becomes 55.35-9.30=46.05 cents/M std.cu.ft.

Effect of Fuel Cost. The effect of variation in fuel cost is shown in Figure 2. Costs of utilities at two different fuel costs have been shown in Table 9. The effect of fuel cost on the over-all cost

lyst is dependent upon two factors initial cost and catalyst life. Initial cost must include the cost of catalyst delivered at the converter plus the cost of



Fig. 3. Methanization cost.

dumping the spent catalyst and refilling the converter. Figure 3 shows the relationship between converter hourly space velocity (cu. ft./cu. ft./hr.), catalyst cost (\$/lb.) and methanization cost (¢/M std.cu.ft. of pipe-line gas). It must be noted that hourly space velocity is calculated upon the basis of purified raw gas charged to the reactor, independent of recycle rate. Cost is based upon the final pipe-line gas following removal of carbon dioxide and water. In this figure it has been assumed that catalyst productivity is constant.

For this study the catalyst has been assumed to be nickel-alumina precipitated on 5%-in. ceramic Raschig rings or nickel-alumina Raschig rings. The cost of such a catalyst is estimated to be \$1.25/lb. (10). Its productivity has been assumed to be 65 M cu.ft. of pipeline gas/lb. (equivalent to six months' life at 2,500 space velocity). This is equivalent to a catalyst cost of 1.92 cents /M std.cu.ft. of pipe-line gas.

Figure 3 demonstrates that the overall cost of methanization is slight. The limiting conditions appear to be a minimum space velocity of 600 coupled with a maximum catalyst cost of \$1.25/lb. Under these conditions the cost of methanization is approximately 1.77 cents/M std.cu.ft. If space velocity can be raised to 5,000 and catalyst cost reduced to \$0.625/lb., methanization will yield a credit of 0.03 cents. Commercial operations can be expected to fall within these limits. Thus the maximum variation in methanization costs is 1.80 cents/ M std.cu.ft. Such a range is indicative of the small effect that methanization has upon the cost of the process as a whole.

Process Efficiency. The over-all thermal efficiency of coal conversion has been calculated. The input, shown in Table A, is based upon gas generator and boiler fuel charged.

It should be mentioned that the efficiency is essentially independent of the by-products recovered from the coal. When stocks with higher amounts of recoverable by-products are charged to the generator the amount of recoverable tar and oil will increase but it will be necessary to charge additional coal in order to produce the same amount of CO and H₂. These two effects will ap-

Carbon 5% Cr	0.0	5.4	. '	'in	i.			-	i	*	٠		*					30,0
Type 3	24,	18	%	. 1	Ci	r,	-8	19	6	N	8	1	st.	en	el			28
Cast ir	991																	- 5
Copper																		7
Admira	kv	III.	etr	al.		_		Ċ										3
80-20	Cun	PO-	mi	cl	r a	ā												-
Tin																		
																		1

proximately balance, resulting in practically unchanged efficiency.

Requirement of Construction Materials. It has been estimated that a plant designed to produce 100 million std.cu.ft./day of pipe-line gas will require materials of construction as given in Table B.

From this it can be seen that a plant designed to produce 300 million std.cu. ft./day of pipe-line gas would require approximately 94,000 tons of iron and steel and 3450 tons of nonferrous alloys.

By comparison, delivery of the same amount of gas at the plant site from the Texas gas fields can be assumed to require about 800 miles of 26-in. pipe line. Such a line would require approximately 200,000 tons of steel if centrifugal compressors and gas-turbine drives are used. Reciprocating compressors would increase the requirements for cast iron and nonferrous materials. Thus it can be seen that the coal-to-gas plant requires less than half the steel and other metals of a pipe line of the same gas capacity.

In this comparison the steel required by the coal mining and preparation plants and by the gas production and gathering systems has not been considered. This also would heavily favor gas from coal.

Summary

It has been estimated that the investment of a plant designed to produce 100 million cu.ft./day of high-B.t.u. pipeline gas is approximately \$52.5 million. The cost of larger plants will be proportional to their size. The cost of producing the gas has been shown to be 55 cents/M std.cu.ft, when the charging stock is a noncaking coal or char having a heating value of 26 million B.t.u./ton and containing no tar-forming materials, available at \$4.00/ton.

This study has shown that the cost of methane from coal is closely related to the cost of coal. With fuel costing \$4.00/ton, fuel represents 45% of the cost of gas (at \$8.00/ton it is 60%). The over-all thermal efficiency of this process compares favorably with other processes for converting coal into more readily available forms of energy.

It has also shown that more than 90% of the cost of producing high-B.t.u. pipe-line gas lies in the production of the purified synthesis gas. Therefore, efforts to reduce the cost must be directed toward reducing the cost of the synthesis gas. Proper selection and pretreatment of the coal to allow its introduction into the gas generator without prior removal of its tar and oil content will effectively reduce its cost, resulting in lowered gas cost.

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The authors are grateful to the Southern Natural Gas Co. for the encouragement and assistance which was given the project on which this paper is based. The assistance of Mr. Frederick Fussman in making a number of the calculations and of Mr. E. G. Clark, Jr., for much of the layout work on which the engineering estimates were based, is appreciated.

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Discussion

- H. S. Anders (Standard Oil Develment Co., Elizabeth, N. J.): Will you explain further, if possible, the sulfurremoval process.
- H. R. Jones: It is a process developed in Germany and employs a selective solvent at low temperatures. That is all we are at liberty to say at present. It is a process proven on pilot plant scale and is going to be used on a plant scale at a Fischer-Tropsch plant which is now being built in South Africa.

Loyal Clarke (Day & Zimmermann, Philadelphia 3, Pa.): For the coking coal, such as the Pittsburgh steam coal, what pretreatment would you use?

H. R. Jones: Pretreatment can be done in several ways: by oxidation, by low-temperature carbonization, and by weathering. There is a new process of controlled oxidation which can also accomplish the same result.

Loyal Clarke: If you did it by lowtemperature carbonization and took your gas from that and added it to your methane, could you thereby reduce the

over-all cost?

H. R. Jones: Yes, you could, but you must remember that if you do that you are putting in heat to give you your initial carbonization. We have not studied coal carbonization because there are other companies much better prepared to give information on coal preparation but we have assumed for the purpose of this paper, that noncaking coal is available at the plant site and we have taken \$4.00 as the cost laid down in our stockpile.

Anonymous (Esso Standard Oil Co., Baton Rouge, La.): Have you had any estimates on when it might be competitive, taking into consideration the trends

in natural gas and coal prices, the demand for natural gas, for various chemicals, etc.?

H. R. Jones: We do not have an estimate of the time when pipe-line gas from coal will be competitive with natural gas. As you indicate, the question is a complex one because of the several factors involved. On the basis of present trends of these variables, we do believe that pipe-line gas from coal will be competitive with pipe-line natural gas in the not too far distant future.

Anonymous: Is gasification in the vein itself practical? I hear it has been carried on in some of the Alabama veins.

H. R. Jones: The work done at Gorgas, Ala., has not yielded anything but a low B.tu. gas. Air is being used as a means of gasification. The Bureau of Mines has indicated that the gas coming up is suitable for gas turbines. I don't think it has made any further claims at present.

C. M. Henderson (Linde Air Products Corp., Tonawanda, N. Y.): I didn't hear the price or purity of oxygen that you might be using in your process.

H. R. Jones: This is tonnage oxygen of 95% purity. The cost of the oxygen depends upon the cost of the utilities.

We do have an attractive price for oxygen here, i.e., it ran \$3.37/ton based on \$4.00 coal. Then the cost of compression was about 60 cents, making it just about \$4.00 a ton going into the Lurgi unit.

C. M. Henderson: Have you given any consideration to the use of lower purity oxygen in this process and how

it might affect the costs?

H. R. Jones: It is not practical to go much lower than 95% purity because all the nitrogen which remains in the oxygen is going to remain as a diluent in the gas. A purity of 90% would reduce the B.t.u. value of the gas so it would not be possible to make 900 B.t.u.'s/cu.ft.

C. M. Henderson: Have you the figure for how many tons of oxygen per ton of methane can be produced?

H. R. Jones: In this setup we have twenty-one Lurgi generators in operation with two as spares. They consume 2100 tons/day of 95% oxygen and produce 100 million std.cu.ft./day or 2180 tons/day of pipe-line gas. This is approximately one ton/ton.

(Presented at A.I.Ch.E. Forty-fourth Annual Meeting, Atlantic City, N. J.)

PRACTICAL THERMODYNAMICS

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A first lecture in thermodynamics, a simplified version of a complex study. Here two authors approach the subject in a vigorous manner which will clarify its practical applications to chemical engineering problems.

THERMODYNAMICS in its broad aspect is the philosophy of energy. Energy itself is entirely a concept of the human mind. The title therefore connotes a practical philosophy of a mental concept, energy. The philosophy herein suggested has proved more practical than the classical presentation in that it more quickly becomes a powerful tool of the student. It is not a method of solving problems by the application of equations howsoever derived.

Heat, Work and Internal Energy

One of our first sense perceptions is the distinction between hot and cold. Two bodies when placed in contact interact to approach the same degree of hotness, or, as we say, the temperature. In order to explain these changes in condition we say energy is transferred from a hot body to a cold body and we have formed the habit of saying that heat (energy) flows from the body at the higher temperature to the body at the lower temperature. According to this common usage, heat designates that form of energy in transition which is caused to flow by a difference in temperature. The difference in temperature between two bodies is a measure of the potential available for overcoming resistance to the flow of heat (energy) between these bodies, and we say temperature is the intensive factor of heat.

The term heat has a definite meaning only as the energy in transition or transferred in this manner. Whatever energy has been received by a body becomes part of the energy content or internal energy of that body and can no longer be identified as heat. These definitions may appear arbitrary, but they conform to common usage. In any

case the definitions must be precise for an accurate understanding and exchange of ideas.

As a means of clarifying the distinction between heat (energy in transition to the system designated by q) and the increase in internal energy (ΔU), consider a closed system of constant volume composed of a pail of water containing an agitator. The system is designated as a closed system because no material of any kind is to be added to or taken from the system during the process to be considered and not because its volume is constant. It has been determined that the total system (pail, agitator and water) has a "water equivalent" of 20 lb. of water, that is, 20 B.t.u. of energy are required to increase the temperature of the system 1° F.

If the temperature of the system is increased from 70° F. to 90° F, by absorption of heat from hot gases from a fire, we say the energy content of the system has been increased (ΔU) by 400 B.t.u. Because there was no source of this energy other than that transferred from the hot gases we conclude that the 400 B.t.u. of energy was acquired by heat transfer to the system and therefore q = 400 B.t.u.

Exactly the same change in the condition of the system may be brought about without the transfer of any heat whatever. By driving the agitator mechanically, as by lowering weights retarded by the agitator, the system may absorb 31,120 ft. lbs., or 400 B.t.u. of energy and the temperature thereby increased from 70° F. to 90° F. As before this energy cannot be identified as mechanical energy or work but simply as an increase in internal energy $(\Delta U = 400 \text{ B.t.u.})$. Conforming to common usage the work done on the closed system (-w) is 400 B.t.u. because q = o.

Following the last described process it would be possible to remove 400 B.t.u. of energy $(-\Delta U)$ from the closed system as heat (-q) thereby bringing the system back to the original state of 70° F. The total change resulting from these two processes would be simply the conversion of 31.120 it. of potential work energy into 400 B.t.u. of heat.

Energy (Heat) Capacity. In the example cited, the increase in the internal energy of the system may be expressed in terms of the increase in temperature. The increase in energy per degree rise in temperature at constant volume, $(\partial U/\partial T)_v$ may be multiplied by dT and the expression $(\partial U/\partial T)_v dT$ integrated over the temperature limits. The expression $(\partial U/\partial T)_v$ designated by C_v is generally miscalled the heat capacity (or specific heat), at constant volume although it may have no more relationship to heat than it does to work.

Entropy. Energy may be transferred in the form of heat from a mass of material without the material undergoing any change in temperature as when steam is condensed to water at a constant temperature. This energy transferred as heat is related to a change in some property of the system other than temperature. This property must be an extensive property whose value depends directly upon the extent of the system. The change in the value of this extensive property must be proportional to the heat which is absorbed or given off by the material at the specified temperature.

This extensive property is called entropy (5). It bears the same relationship to thermal effects as weight bears to potential energy effects. If 1000 ft. lb. of energy are removed as potential energy from a system at a constant elevation of 100 ft., the weight of the system has been decreased by ten pounds force (foot pounds force per foot). Similarly, if 1000 B.t.u. are removed as thermal effects or heat from a system at a constant temperature of 500° R.,

Lost Work. Because, as commonly used, \$TdS\$ does not differentiate between heat and loss of potential energy, another expression (lw) is used to designate all potential work dissipated in overcoming resistances or in irreversibilities or "lost work." It represents the energy that might have been evident as work if it had not been so dissipated. Accordingly

$$\int TdS = q + (lw), \qquad (1)$$

The First Law

According to these conceptions the accumulated experience of mankind indicates that energy and mass may change in form but are not destroyed in any process. This First Law is the basis for the energy and material balances familiar to all chemical engineers. For the general case of an open system, that is, a system to or from which material as well as energy may be added or removed, the accumulation of energy and mass in the system equals the energy and mass removed.

Accumulation,
$$\Delta [U+mgZ+mv^2/2] =$$
 Energy added with mass,
$$[U_i+P_iV_i+m_igZ_i+m_iv_i^2/2] +$$
 heat added
$$q -$$
 Energy removed with mass,
$$[U_e+P_eV_e+m_egZ_e+m_ev_e^2/2] -$$
 work done
$$v$$
 (2)

the entropy of the system has been decreased $(-\Delta S)$ by 2 B.t.u./° R.

In heat transfer where a quantity of energy is transferred as heat from a body at a high temperature T_1 to a body at a lower temperature T_2 , the quantity of energy removed from the hot body $(-\Delta U)$ as changes in thermal effects $(-\int T_1 dS_1)$ is numerically equal to the quantity of energy absorbed by the colder body (ΔU_2) as thermal effects $(\int T_2 dS_2)$. Since T_2 is less than T_1 , it follows that ΔS_2 is greater numerically than ΔS_1 .

The increase in internal energy by thermal effects $\ell fTdS$) may be brought about without ℓ the absorption of heat but by the dissipation of mechanical or other forms of energy in overcoming resistance. In the case of the pail of water discussed above fTdS equals 400 B.t.u. in either case, whether the energy was supplied by the absorption of heat or by the dissipation of potential work.

The expression $\int TdS$ represents the increase in energy content (ΔU) due to or accompanied by thermal effects and includes both those thermal effects created by heat transfer and those thermal effects created by the dissipation of mechanical or potential energy as in overcoming resistances.

where U = internal energy; as written this term includes all the energy associated with matter except the energy related to position and motion. What effects are or are not included in U is a matter of convenience. The important consideration is a clear and definite understanding as to what is included.

m = mass

g = acceleration of gravity

Z = elevation above a datum plane mgZ = energy of position, potential energy

v = velocity

 $\frac{mv^2}{2} = \text{energy of motion, kinetic energy}$

P = pressure

V = volume

PI' = mechanical energy carried by material, the energy required to push the material into or out of the system

q = energy in transition or transferred directly to system as heat independent of any material transfer

w = work or energy other than heat transferred directly from system independent of any material

Subscripts i and e denote properties of material in and out, or of inlet and exit streams, respectively; properties of the material contained within the prescribed boundaries of the system are indicated by symbols without subscripts.

If the system is closed, that is, no material crosses the boundaries of the system, the first law leads to the simplified equation:

$$\Delta[U + mgZ + mv^2/2] = q - w \tag{3}$$

Open and Closed Systems

Actually the only difference in the two systems, open or closed, is in the point of view used in defining the system. Whichever is more convenient should be used as both viewpoints lead to the same conclusions.

Example

An insulated tank of 50-cu.ft. capacity containing saturated steam at 14.7 lb./sq.in. abs. is connected to a steam line maintained at a constant pressure of 50 lb./sq.in.abs. and 10° F. superheat. Steam is allowed to flow slowly into the tank until the pressures become equal at 50 lb./sq.in.abs. Compute the final condition of the steam in the tank, assuming no heat transferred from the tank and neglecting any change in temperature or volume of the tank itself.

Open System Analysis. The system is defined as the steam within the tank at any instant, and the mass of the system will vary during the course of the process. The increase in internal energy of the system $(U_0 - U_1)$ equals the energy carried into the system by the steam which flows into the tank, $(U_1 + P_1V_4)$, because q = 0. w = o, nothing leaves the tank and changes in position and motion are negligible.

$$\Delta U = U_2 - U_1 = U_4 + P_4 V_4 \qquad (4)$$

Since, $m_4 = m_0 - m_1$ by mass balance, and H = U + PV by definition (5)

$$\left[\left(\frac{U_1}{m_2}\right)(m_2)\right] - \left[\left(\frac{U_1}{m_1}\right)(m_1)\right]$$

$$= \left(\frac{H_4}{m_1}\right)(m_2 - m_1) \qquad (6)$$

In Equation (6) aft terms are known except (U_a/m_a) and m_b.

From the steam tables:

$$\begin{pmatrix} \frac{U_1}{m_1} \end{pmatrix} = 1077.5 \text{ B.t.u./lb. (saturated at} \\ 14.7 \text{ lb./sq.in.)} \\ \begin{pmatrix} \frac{H_4}{m_4} \end{pmatrix} = 1179.44 \text{ B.t.u./lb. (superheated} \\ 10^n \text{ at } 50 \text{ lb./sq.in.)} \\ m_4 = \frac{50}{V_1/m_1} = \frac{50}{26.8} = 1.865 \text{ lb.}$$

However, the steam tables constitute another equation between specific energy another equation between specime (U/m), pressure, and volume or temperature, and since P_0 is 50 lb./sq.in.abs. and the volume V_0 is known there are two independent equations for the two unknowns

and m2 may be determined by Equation (6)

$$\left[\left(\frac{U_0}{m_0} \right) (m_0) \right] - \left[(1077.5) (1.865) \right]$$

$$= \left[(1179.44) (m_0 - 1.865) \right]$$

Assume for trial that $T_s = 400^{\circ}$ F. Since $P_s = 50$ lb/sq.in.abs. the steam tables give $(U_s/m_s) = 1141.9$ B.t.u./lb. and $(V_s/m_s) = 10.065$ cu.ft./lb. Since m_s equals the volume of the tank divided by the specific volume of the steam in the final state, $m_b = 50/10.065 = 4.955$ lb. These values satisfy the above equation. Therefore the assumed final conditions of the steam in the tank, $P_2 = 50$ lb./sq.in.abs. and $T_0 = 400$ F. are correct.

Closed System Analysis. The same process may be conducted in the same way with the boundaries of the system so defined as to include at all times all the fluid finally in the tank. This system includes the steam initially in the tank, and the steam initially in the steam line which flows into the tank during the process. So defined, the system is a closed system of changing volume with work being done on the system but with no heat transfer. The work done on the system is that required to force the steam in the main line into the tank and is equal to the pressure exerted by this steam times the initial volume of this steam initially in the steam line which flows into the tank

For this closed system, q = o and with negligible gravitational and kinetic effects, Equation (3) becomes

$$\Delta U = U_s - U_1 = -w \qquad (7)$$

In this closed system the initial internal In this closed system the initial internal energy U_i includes both U_i and U_i of the open system, Equation (4); and —w of Equation (7) equals P_iP_i of Equation (4). Therefore Equation (7) may be reduced to Equation (4). This may be made clear as follows:

$$U_{z} = \left[\left(\frac{U_{z}}{m_{z}} \right) (m_{z}) \right]_{t}$$

$$U_{1} = \left[\left(\frac{U_{1}}{m_{z}} \right) (m_{1}) \right]_{t} + \left[\left(\frac{U_{1}}{m_{z}} \right) (m_{1}) \right]_{t}$$

where subscript t refers to the accumulator tank and s to the main steam line

$$v = \left[P_s\left(\frac{V_1}{m_1}\right)(m_1)\right]_s$$

$$(m_1)_i - (m_1)_i = (m_1)_i$$

Substituting the above relationships

Substituting the above relationships in Equation (4) gives (8)

$$\begin{bmatrix}
\left(\frac{U_2}{m_z}\right)(m_z)\end{bmatrix}_{\epsilon} - \left[\left(\frac{U_1}{m_1}\right)(m_\lambda)\right]_{\epsilon}$$

$$= \left[\left(\frac{H_1}{m_z}\right)(m_1)\right]_{\epsilon} (8)$$

which is identical to Equation (6) since

$$\begin{bmatrix} \left(\frac{U_1}{m_1}\right)(m_1) \end{bmatrix}_i = \left[\left(\frac{U_1}{m_1}\right)(m_1) \end{bmatrix}$$
 and
$$\begin{bmatrix} \left(\frac{U_2}{m_2}\right)(m_2) \end{bmatrix}_i = \left[\left(\frac{U_2}{m_2}\right)(m_2) \end{bmatrix}$$
 and
$$\begin{bmatrix} \left(\frac{H_1}{m_1}\right)(m_3) \end{bmatrix}_i = \left(\frac{H_4}{m_4}\right)(m_0 - m_1)$$

Thus, the same result, as would be ex-pected, is obtained irrespective of whether the system is defined as closed or open.

Steady Flow

In steady-state flow, the properties of the system do not change with time, and there is no accumulation of energy or mass in the system. The first term of Equation (2) is zero, and the equation can be rearranged to yield the familiar flow equation:

$$\begin{bmatrix} U_e + P_e V_e + m_e g Z_e + \frac{m_e v_e^2}{2} \end{bmatrix} - \begin{bmatrix} U_i + P_i V_i + m_g Z_i + \frac{m_i v_i^2}{2} \end{bmatrix} = q - w$$
(9)

The Second Law

The second law may be regarded as a work balance corresponding to the energy and material balance of the First Law. Wherever the engineer is concerned with the efficiency of an operation, the work balance is far more important than the simple energy bal-

Equation (2) may be used as follows with the elimination of heat, q, to express a work balance.

$$\begin{split} H_i + m_i g Z_i + \frac{m_i v_i^2}{2} + q \\ &= \Delta \left(U + mg Z + \frac{m v^2}{2} \right) + \\ H_c + m_c g Z_c + \frac{m_c v_c^2}{2} + w \end{split}$$

By an entropy balance.

$$S_i + q/T + \frac{(lw)}{T} = \Delta S + S_e$$

$$q_T = T\Delta S + TS_e - TS_i - (lw)$$
(10)

For the temperature T,

$$H_i - TS_i + m_i g Z_i + \frac{m_i v_i^2}{2}$$

$$= \Delta \left(U - TS + mgZ + \frac{mv^2}{2} \right) +$$

$$H_e - TS_e + m_e g Z_e + \frac{m_e v_e^2}{2} +$$

$$w + (lw) \qquad (11)$$

Isothermal Process

For an isothermal process in which material supplied at conditions represented by subscript i is to be converted completely into material of the conditions represented by subscript e and delivered with no accumulation of material or energy during this transfer, the work obtained during this transformation and delivery under the given conditions is represented by the following equation obtained by combining terms and substituting the value G in Equation (11).

By definition

$$G = U + PV - TS = H - TS$$

$$(12)$$

$$(w + lw)_T = w_{rev.} = (G_i - G_e)_T +$$

$$(w + kv)_T = w_{rev.} = (G_i - G_e)_T + mg(Z_i - Z_e)_T + m/2(v_i^2 - v_e^2)_T$$

(13)

The maximum quantity of work that could be obtained from such a process which involves only the material transferred from state i to state e is the sum of, w + lw. This quantity is referred to as the reversible work. It is determined entirely from the properties of the material in the two states. The value for the reversible work, wree, represents the maximum energy which is available to overcome resistance to the indicated change in state. When there is no energy available to overcome resistances to an indicated change from one state to another state the two states are considered to be in neutral or balanced equilibrium as there is no tendency for state I to transform into state e and no tendency for state e to transform into state i funder the conditions stated.

This equation is therefore of direct use not only in indicating the quantity of work required to bring about a given anothermal change but also to indicate the conditions of isothermal equilibria between two states under the restraints included in the equation.

Example

A natural gas well one mile deep has been shut in for a long time so that equilibrium conditions exist throughout the length of the well. The pressure at the top of the well is 2000 lb./sq.in.abs. The composition of the gas at the top is 90% methane and 10% ethane. The temperature is uniform and constant at 100° F, throughout the well. Compute the pressure and ethyposition at the bottom of the well.

In this case there is no chemical reaction involved between the constituents. The only changes are in mole fractions of the methane and ethane. Therefore equilibrium exists between the methane at the top of the well and methane at the bottom of the well, and likewise for ethane. Writing the work balance for each of the two constituents of the gas and placing to the constituents.

$$(G_* - G_*)_T + Z_* - Z_* = 0$$

Assuming ideal gases, for simplicity, and setting

$$G = \frac{RT}{M} \ln \left(\frac{P_s}{P_t} \right)$$

$$\frac{RT}{M} \ln \left(\frac{x_s P_s}{x_s P_s} \right) = Z_t - Z_s$$

For methane:

$$\frac{1544(560)}{16} \ln \left(\frac{x_e P_e}{0.9(2000)} \right) = -5280$$

$$\ln \left(\frac{x_e P_e}{1800} \right) = 0.0977$$

$$\frac{x_o P_o}{1800} = e^{0.0071} = 1.1026$$
 $x_o P_o = 1984.68$ (14)

For ethane:

$$\frac{1544(560)}{30} \ln \left[\frac{(1-x_e)P_e}{0.1(2000)} \right] = -5280$$

$$\ln \frac{(1-x_e)P_e}{200} = 0.1832$$

$$\frac{(1-x_e)P_e}{200} = e^{0.399} = 1.1978$$

$$P_e - x_e P_e = 239.56 \qquad (15)$$

Solving the two simultaneous Equations (14) and (15).

 $P_s = 2224$ lb./sq.in.abs. $x_s = 0.892$ mole fraction methane $1 - x_s = 0.108$ mole fraction ethane

Deviations from ideal gas behavior may be included by incorporating the compressibility factor with the assumption of ideal solutions and the activity coefficient, giving a pressure of 2300 lb.sq.in.abs. and a composition of 88% methane and 12% ethane at the bottom of the well.

Electrical Effects

If electrical effects are present, they are most conveniently introduced in the same way as the potential energy. Equation (13) then becomes

$$(G_e - G_i)_T + mg(Z_g - Z_i + \frac{m}{2}(v_e^2 - v_i^2) + NFE_e - NFE_i = w_{ree.}$$
 (16)

which equation may also be written as follows for an isothermal change between two states of unit mass:

$$\Delta G_T + \Delta Z + \frac{\Delta(v^2)}{2} + NF\Delta E = -w_{rev.}$$
(16a)

where

N = number of hydrogen equivalents F = Faraday

E = electrical potential

This approach toward isothermal equilibrium considers only the neutral or balanced equilibrium between two states or conditions. It corresponds to, but is not the same as, the neutral or balanced equilibrium state and must not be confused with the so-called stable or unstable equilibrium states of a system in respect to infinitesimal changes treated by Gibbs.

Availability

In engineering practice the system or the material under consideration is always related to its immediate surroundings and the interaction of the surroundings with the system is considered in determining the useful work that can be obtained from a process. In general the surroundings possess definite properties of temperature and pressure. The temperature of the surroundings determines the lowest temperature at which heat may be transferred to the surroundings from the system and the highest temperature at which heat may be absorbed from the surroundings.

Consider material (which might be steam) flowing through a system (which might be an engine). If all heat transferred to the surroundings is so transferred by reversible heat engines operating between the temperature in the system, T, whatever it may be and the temperature of the surroundings, T_o, Equation (10) becomes

$$q = T_o \Delta S + T_o S_c - T_o S_i - (lw)_o$$
(17)

A work balance corresponding to these conditions of reversible heat transfer is obtained by eliminating, q, from Equation (9) by substituting Equation (17) with no accumulation, $T_o \Delta S = 0$.

$$w + (lw)_o = (H_i - H_e) - T_o(S_i - S_e)$$

 $+ mg(Z_i - Z_e) + m\left(\frac{(v_i^2 - v_e^2)}{2}\right)$
(18)

The above expression represents the decrease in availability referred to the

temperature T_{oi} of the material in flowing from i to c and is frequently represented by ΔB . It is applicable to material in steady flow and represents the decrease in ability of the material to do useful work in cooperation with its surroundings in flowing from state i to state c. If the temperature of the material is constant and equal to the reference temperature (of the surroundings) Equation (18) becomes identical with Equation (13).

Similarly, for closed systems in which no material is transferred across the boundaries of the system, the work balance may be written as follows:

$$w + (lw)_o = \Delta U - T_o \Delta S + mg\Delta Z + \frac{m\Delta(\tau^2)}{2}$$
 (19)

For the case where the system expends work energy by the movement of its boundaries against the pressure of the surroundings, P_o , the amount of energy $P_o\Delta V$ is not available to overcome resistance, or is not useful work, and Equation (19) is frequently written,

$$[w + (lw)_o + P_o\Delta V] = w_{uneful} = \Delta U -$$

$$T_o\Delta S + P_o\Delta V + mg\Delta Z + \frac{m\Delta(v^2)}{2}$$
 (20)

(Presented at A.I.Ch.E. Rochester (N.Y.) Meeting.)

THE MECHANICS OF DROPS

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As a preliminary to a general study of mass transfer in fluid particle systems, a review and analysis were made of the mechanics of drops. The general review presented includes both the gross motion of drops and the detailed motion in and around individual drops. The emphasis of the review is on new concepts and correlations in connection with the effect of acceleration on drag, the equilibrium distortion, and the internal circulation caused by skin friction.

GROSS motion means the time-dis-tance-velocity relationships of the drop as a whole. As a typical case, consider the force balance for the vertical motion of a drop through a stagnant continuous phase of infinite extent:

$$\rho_{i} \frac{\pi}{6} d^{3} \frac{dV}{d\theta} = \frac{\pi}{6} d^{3}g(\rho_{i} - \rho_{o}) - c_{D} \frac{\pi}{4} d^{2} \frac{\rho_{o}|V|}{2} V$$
(1)

The drag coefficient, c_D , is defined as,

$$c_{D} = \frac{\text{Drag}}{(\text{Frontal Area}) \left(\frac{\rho_{0} V^{2}}{2g_{c}}\right)}$$
(2

Because of the undefined shape of a drop, the geometry is usually assumed as spherical, and the value of c_D allowed to vary to adjust this assumption to the actual facts. To solve Equation (1), the drag coefficient must be known as a function of the other variables. Dimensional analysis for this case yields,

$$e_D = \phi \left(Re, Su, Wt, Ac, \frac{\rho_0}{\rho_t}, \frac{\mu_0}{\mu_t} \right)$$

$$Rc = \frac{dV \rho_0}{\mu_0}$$
(4)

$$Rc = \frac{dV\rho_o}{\mu_o}$$

$$S_M = \frac{g_c\sigma d\rho_o}{\mu_o^2}$$
(5)

$$Wt = d \left[\frac{4}{3} \frac{g \rho_0 |\rho_i - \rho_0|}{{\mu_0}^2} \right]^{\frac{1}{6}}$$
(6)

$$Ac = \frac{d}{V^2} \frac{dV}{d\theta}$$
 (7)

The analysis of the motion is greatly complicated by the period of acceleration and by the fluid nature of the drop. Accordingly, the extension of Equation (3) to allow for containing walls and for continuous-phase motion and turbulence will not be considered, although it should be noted that these effects are often a major source of disagreement between experimenters. For steady motion of solid shapes, cp becomes a function of Re alone, as shown in Figure 1 by the lines for spheres and disks. These lines are obtained by a critical comparison and evaluation of the data in the literature.

A major purpose of the remainder of this paper is to provide a means of estimating the more complicated function of Equation (3), although knowledge of distortion and detailed motion is also of value in itself.

Effect of Acceleration. The most accurate and convenient methods of determining the drag coefficient function are either a direct determination of drag in a wind tunnel or the measurement of terminal velocities of falling bodies.

Since such measurements are limited to systems of steady flow, the important effect of acceleration on the drag has often been overlooked. Such otherwise excellent treatments of particle motion as those of Lapple and Shepherd (16) and Dallavalle (9) have made no mention of accelerational drag. Unfortunately, the few data available on acceleration are limited to solid shapes. The combined effect of fluidity and acceleration can merely be conjectured.

Acceleration in Creeping Motion. Fortunately, a mathematical solution for the case of very slow, or "creeping" motion is available for a guide to the effect of acceleration. The solution, first proposed by Bassett (2, 3) was completed by Picciati (20) and Boggio (5). The whole was summarized by Bassett in a later paper (4). His final equation can be reduced to dimensionless variables and simplified to:

$$\begin{split} \frac{V_t - V}{V_t - V_o} &= \frac{\sqrt{a}}{\sqrt{a} - \sqrt{\beta}} \chi \left(\frac{4\beta q}{\rho_o} \frac{\rho_t}{\rho_o} Ti \right) \\ &= \frac{\sqrt{\beta}}{\sqrt{a} - \sqrt{\beta}} \chi \left(\frac{4\alpha q}{\rho_o} \frac{\rho_t}{\rho_o} Ti \right) \end{split}$$
(8)

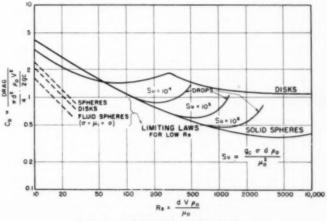


Fig. 1. Drag coefficients of spheres, disks, and draps.

Spheres and disks-compilation of literature data. Drops-Equations (26), (27), (28), and (30), and Table 1. Limiting laws (15).

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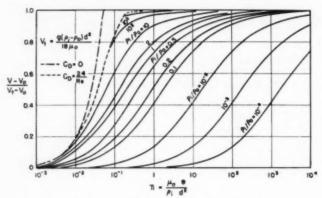


Fig. 2. Velocity-time curves for spheres in creeping motion. Equations (8) to (12), (4).

where

$$\chi(x) = e^{x} erfc \sqrt{x}$$

$$= e^{x} \frac{2}{\sqrt{\pi}} \int_{\sqrt{x}}^{\infty} e^{-ut} du$$

$$Ti = \frac{\mu_o}{\rho_i} \frac{\theta}{d^2}$$
(9)

$$q = \frac{9p_0}{2p_i - p_0}$$
 (10)

$$a = \frac{q}{2} - 1 + \sqrt{\left(\frac{q}{2} - 1\right)^2 - 1}$$

$$\beta = \frac{q}{2} - 1 - \sqrt{\left(\frac{q}{2} - 1\right)^2 - 1}$$
(12)

When $\rho_i/\rho_o > 0.625$, a and β are complex. This disturbed Bassett, who thought there was some physical mistake in his solution. However, the imaginary terms cancel out and values calculated from Equation (8) are shown in Figure 2. Values were calculated by both direct and series computations, as demanded $\alpha = \frac{q}{2} - 1 + \sqrt{\left(\frac{q}{2} - 1\right)^2 - 1}$ and series computations, as demanded by the values of α and β . The lines for no acceleration of the product of α and β and β are considered. no drag, $c_D = 0$, and for no accelera-(11) tional drag, $c_D = 24/Re$, were obtained

directly from Equation (1) using V_t from Stokes' law. The significant effect of acceleration is clearly shown by the longer time required to reach the same velocity. This effect is shown even more clearly in Figure 3, which gives cp/cpot the ratio of the true drag coefficient to that for steady motion, as a function of V/V_t for the case of zero initial velocity. In the region of complex α and β $(\rho_i/\rho_o > 0.625)$, c_D/c_{D_o} cannot readily be evaluated for $V/V_t < 0.7$, but from Figure 2 and the rapid change of c_D/c_{D_0} with ρ_i/ρ_o just below 0.625, it is to be expected that the function rapidly reduces to unity.

Effect of Acceleration at Higher Reynolds Numbers. Laws (17) has reported measurements of the acceleration of drops, and a number of workers have obtained measurements of the acceleration of solid spheres. Allen (1) gives a few points for a single steel sphere in water ($Re_t = 2480$). Although all of these correspond to velocities greater than 65% of the terminal value, the lowest velocity points correspond to drag coefficients 10 to 20% higher than those for steady motion at the same Reynolds number. Cook (8) reports data for a large spherical mine case so balanced that the net weight was 1 lb. while the displacement was 1081 lb. Again, the drag coefficients during the acceleration period are much larger than those for steady motion.

Schmidt (25) studied wax spheres in water $(\rho_t/\rho_o \approx 1.0 \text{ to } 1.1)$ and balloons

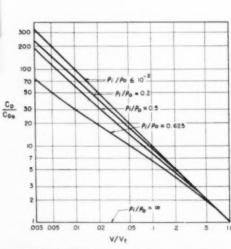


Fig. 3. Effect of acceleration on drag of spheres in creeping motion. Equations (8) to (12), (4) with $V_n = 0$.

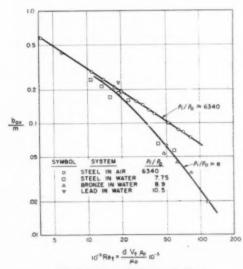


Fig. 4. Average carried masses of spheres. Correlation of values (18, 19) for average over entire acceleration period.

in air $(\rho_i/\rho_0 \approx 0.60$ to 1.0). His curves of velocity vs. time show a strong oscillation, which makes determination of drag coefficients by obtaining slopes practically impossible. Nevertheless, the acceleration is slower than would be predicted using steady flow drag coefficients, thus confirming qualitatively the previously indicated dependence of drag on acceleration.

The most extensive reported study of the acceleration of spheres is that of Lunnon, who worked with rubber, wood, stone, and steel spheres in air (18), and bronze, lead, and steel spheres in water (19). In addition to his original time-distance data, Lunnon evaluated steady flow drag coefficients, c_{Dg} , and carried masses, b, for each sphere, using an equation which can be rewritten in the present notation as,

$$c_D = c_{D_0} + \frac{4}{3} \frac{\rho_i}{\rho_o} \frac{b}{m} Ac \quad (13)$$

This is used in Equation (1) and the values of c_{B_0} and b determined by placing the best straight line through a plot of $dV/d\theta$ vs. V^2 . Values of b_{av} reported by Lunnon can be reasonably well correlated as b_{av}/m vs. Re_t (the terminal Reynolds number) as shown in Figure 4. The c_{D_0} values check reasonably well with the steady-state curves. Unfortunately, these averages apply only to the acceleration period as a whole, since the plots of $dV/d\theta$ vs. V^2 are actually sinuous curves. Using the average values yields too low an acceleration for the first half a second, too high a value for the next two or three seconds and again too low a value for the remainder of the acceleration period. Fortunately, Lunnon also observed that the motion in air during the first three seconds could also be well described by using a constant drag coefficient of 0.62. This obviously neglects the initial period during which even cpa exceeds 0.62.

Drag coefficients for the acceleration of water drops were calculated from Laws' (17) data by Williams (28). While the chief observed effect is an oscillation referred to below, there is a definite trend, as velocity decreases below about one half the terminal value, toward higher drag coefficients.

As a general rule accelerational drag exists. The few spot checks made with the turbulent region results indicate larger values of c_D/c_{Do} than those for creeping motion. As a first approximation, Figure 3 can be used to estimate the effect of acceleration.

Distortion. Since the drag coefficients are functions of the shape of the moving particle, any distortions would have a marked effect on the motion of a fluid particle. In addition, such distortions would have an effect on the

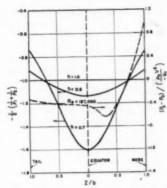


Fig. 5. Pressure and surface force distributions for drops. Pressure distribution (10, p. 497). Surface force distribution—Equation (20).

surface area, and thus on the rate of heat and mass transfer. The distortions are of two basic types; those of an equilibrium nature, and those of an oscillating nature resulting from vibrations about this equilibrium position.

The pressure exerted by the surrounding fluid on a moving sphere is not uniform. In Figure 5 the dashed line, taken from Goldstein (10), shows the pressure variation at the surface with axial distance. On the other hand, within a drop, since the fluid motion is slight, the pressure is uniform except for gravitational head. There is accordingly a difference in pressure across the surface which is supported by the surface forces according to the equation,

$$\rho_i-\rho_s=\sigma\left(\frac{1}{\rho_1}+\frac{1}{\rho_2}\right) \quad (14)$$

Thus the shape of the drop is dictated by the variation of ρ_1 and ρ_2 , the radii of curvature.

Unfortunately, since p_a in turn depends on the shape of the drop and is not known exactly even for a sphere, the theoretical calculation of the shape is impossible. The usual method of assuming that the distorted shape is a spheroid with its axis in the direction of motion will be followed. The equation of the surface is thus

$$\frac{x^2 + y^2}{a^2} + \frac{z^2}{b^2} = 1 \tag{15}$$

The extent of distortion can then be expressed in terms either of the fineness ratio,

$$h = b/a \tag{16}$$

or the eccentricity. When the spheroid is oblate,

$$e = \sqrt{1 - h^2} \tag{17}$$

Since the volume of a spheroid is $4/3 \pi a^2 b$, in terms of the equivalent spherical diameter,

$$a = \frac{1}{2} dh^{-\frac{1}{2}}; \quad b = \frac{1}{2} dh^{\frac{1}{2}}$$
(18)

By the use of elliptic functions, the surface area can be expressed as:

$$\frac{S}{v} = \frac{6}{d} \frac{1}{2h^{\frac{4}{5}}} \left\{ 1 + \frac{h^2}{\sqrt{1 - h^2}} \times ln \left[\frac{1 + h + \sqrt{1 - h^2}}{1 + h - \sqrt{1 - h^2}} \right] \right\}$$
(19)

This equation shows that the correction is not severe as long as h>0.8. For the prolate spheroid, a similar equation can be obtained.

To provide some idea as to whether a spheroidal shape corresponds, even approximately, to the actual one, resulting from the condition of Equation (14), Figure 5 has been prepared. The ordinate plotted has been evaluated by standard geometrical theorems, which lead to:

$$= \frac{\frac{d}{4}\left(\frac{1}{\rho_1} + \frac{1}{\rho_2}\right)}{2} \left\{ \frac{1 + h^2 + (1 - h^2)(z/b)^2}{[h^2 + (1 - h^2)(z/b)^2]^{4/9}} \right\}$$
(20)

By consideration of Equation (14), it is seen that this ordinate is proportional to $p_t - p_s$, so that, since p_t is uniform, except for the linear gravitational effect, the variation with z/b should correspond with that of p_s . The figure shows that the assumption of spheroidal shape is quite reasonable, although, in agreement with the photographic evidence of Laws (17) and Henrickson (13), more distortion is to be expected at the front than at the rear.

Previous Efforts to Predict Distortion. By carrying Stokes' derivation of drag on a sphere to a second approximation, in a somewhat different manner from Oseen, Saito (24) showed that the general equation of motion predicts distortion, even in the region of creeping motion. Complete experimental verification of his equation has not yet been found, but it is interesting that experiment (28) agrees with Saito's equation in predicting a prolate spheroid for mercury drops and an oblate spheroid for water or organic liquids.

In the more useful and interesting range of intermediate and high Reynolds numbers, Spilhaus' recent approach (26) has considerable promise. He suggests that the force tending to separate the drop laterally can be considered as proportional to the area over which it acts and to kinetic head, $\rho_0 V^2/2g_{ev}$ of the continuous phase. The dimensionless proportionality factor, termed the distortion coefficient, is similar to the drag coefficient, and was assumed constant by Spilhaus.

The following analysis is an alternate development of Spilhaus' concept that appears to avoid some of the intuitive steps of his procedure.

Quasi-Thermodynamic Analysis of Distorting Forces. Consider as a thermodynamic system a drop of liquid, together with its surface, which is undergoing a progressively increasing distortion because of an unequalized external pressure. The following assumptions can be made concerning this system:

- The system is reversible. This merely requires that the deformation occur so slowly that the viscous friction within the drop is negligible.
- The volume of the system is constant.
 The system is adiabatic.
- The system is adiatate.
 The system is isothermal. This results from the mechanical nature of surface tension and assumptions (1) and (3).
- The deformed drop is spheroidal. Actually, for the thermodynamic development, the only requirement is axial symmetry, but, for numerical evaluation, a more definite shape is necessary.

The first and second laws of thermodynamics and the concept of surface tension as free surface energy per unit surface yield the equations.

$$-\frac{dW}{da} = \frac{dA}{da} = \sigma \frac{dS}{da}$$
 (21)

Here a is chosen as a convenient measurement of the deformation, since it increases as the deformation becomes more severe. By a consideration of the effect of increasing distortion on each element of surface &S, it is apparent that the work can be evaluated as

$$-\frac{dlV}{da} = \int_{S} \frac{dr}{da} \left(p_a - p_a \right) \delta S$$
 (22)

Since the integrand of this equation is normal in form, it should be possible to obtain some suitable average. Then, by combination with Equation (21),

$$\frac{\sigma}{S} \frac{dS}{da} = \left[\frac{dr}{da} \left(p_s - p_o \right) \right]_{av}$$
(23)

This average value can be considered as the average net pressure causing distortion. Thus, using the distortion coefficient concept,

$$\frac{\sigma}{S} \frac{dS}{da} = \gamma \frac{\rho_0 V^2}{2a} \tag{24}$$

or, in dimensionless terms, using the equivalent spherical diameter,

$$\frac{1}{4} \gamma \frac{Re^2}{Sn} = \frac{d}{2S} \frac{dS}{da} \equiv \phi_1(h)$$
 (25)

The function ψ_1 is then obtained by proper differentiation of Equation (19). Values calculated are included in Table

1. Thus for a given distortion, Reynolds number and surface tension group, the distortion coefficient can be calculated.

Calculation of Distortion from Drag Measurements. Unfortunately, few measurements of the distortion of falling drops have been reported, and those reported are only approximate. However, by assuming distortion to be the only significant difference between the drag of drops and that of spheres, the distortion can be calculated from drag data. Reserving c_D and Re for the values calculated using the diameter of the equivalent sphere, the true values for a spheroid are

$$c_{B}' \equiv \frac{\text{Drag}}{\pi a^2 \left(\frac{\rho_o l^{-2}}{2g_c}\right)} = c_{D} l_l^{\eta_b} \quad (26)$$

$$Re' \equiv \frac{2aV\rho_0}{\mu_a} = Re h^{-1/3}$$
 (27)

Ä	\$ 2	$-\frac{\Delta\psi_1}{\Delta h}$
1.00 .98 .95 .90 .85 .80 .75 .65 .60 .55	.0000 .02110 .02463 .11106 .1700 .2310 .2941 .3593 .4270 .4952 .5640 .6321 .8236	1,055 1,118 1,128 1,179 1,22 1,26 1,31 1,35 1,37 1,36 1,28

h	V2	$-10^{-2}\frac{(\Delta\psi_2)}{(\Delta h)}$
1,00 98 ,95 ,96 ,85 ,80 ,75 ,70 ,60 ,55 ,50	0.0 8.253 21.25 43.03 65.42 88.24 111.5 135.1 159.2 183.0 206.3 228.6	4.126 4.333 4.356 4.478 4.564 4.652 4.72 4.82 4.76 4.66 3.467

	Part C	
		-10^{8} (Δh)
W2	h	(A4)2
0	1.000	2.4
10	.9760	2.31
20	.9529	
30	.9299	2.3
40	,9070	2.26
50	,8844	2.23
60	.8621	2.21
70	.8400	0.0
80	,8180	2.18
90	.7962	2.15
100	.7747	2.15
110	.7532	2.12
120	.7320	2.12
130	.7108	2.1
140	.6698	2.07
150	.6691	2.08
160	.6483	2.1
170	.6278	2.1
180	.6063	2.13
190	.8850	2.15
200	.5635	2.18
210	.5417	2.24
220	.5193	2.28
230	.4965	2.37
240	.4728	2.48

By wind-tunnel measurements at a Re' value of 12,500, Riabouchinsky (22) found the following relation to hold for oblate spheroids of varying eccentricity,

$$\frac{c_{D^{'}}}{c_{D^{*}}} = 1 + (1 - h) \left(\frac{c_{D^{'D}}}{c_{D^{*}}} - 1 \right) \tag{28}$$

In this equation, $c_D{}^o$ for the sphere, $c_D{}^c$ for the spheroid, and $c_D{}^{\prime D}$ for the disk are all evaluated at the same value of Re^c . It is quite reasonable to extend this equation to any value of Re^c , since the disk and the sphere are limiting shapes of a spheroid and do not greatly differ in drag coefficients. Actually, Lamb's derivation (15) of the laws for ellipsoids in the Stokes law region shows that Equation (28) does not quite follow the true function in this region, but the difference is slight and certainly unimportant since it applies at such low Reynolds numbers.

Using experimental values of c_D and Re for drops, Figure 1, and Equations (26)-(28), values of h can be calculated for each set of measurements. Although a trial-and-error solution is necessary, only two or three trials are usually required. Then from the h values, ψ_1 can be obtained from Table 1 and the distortion coefficient calculated by Equation (25).

Experimental Correlation Based on Drag of Falling Drops. The procedure just explained was applied to available data on the drag of drops in gases, which was summarized by Williams (28). Unfortunately, the much more plentiful data on drops in liquids could not be used, since for these data the assumption of no difference between drops and spheres other than the distortion did not appear justified. Data used are all values of terminal velocity in air. They include measurements of Henrickson (13) on water, n-propanol. and nitrobenzene drops, and those of Watson (27) on methylsalicylate drops. but the correlation is based chiefly on Laws' much more accurate measurements of water drops (17).

From the calculated values of γ , it was found that Laws' data, which were already smoothed by him, can be almost exactly represented by the equation,

$$\gamma = 0.0102 \, Re^{6.86} \tag{29}$$

This equation is well supported by Watson's data, but Henrickson's data lead to γ values about 10 to 60% high. However, Williams (28) states that these velocity values are probably not terminal velocities since the distance of fall was not quite sufficient. The assumption that the data do represent terminal velocity would lead to high γ values.

2.74

From Equations (25), (27), and (29), a new function is now defined and evaluated.

$$\phi_2(h) \equiv \frac{4\phi_1 h^{0.117}}{0.0102} = \frac{Re^{2.35}}{Su}$$
(30)

Values of ψ_2 vs. h and h vs. ψ_2 are given in Table 1.

Photographic Observations of Distortion. In making his velocity determinations, Henrickson obtained flash photographs of the falling drops. Observation of these photographs shows that the drops do approach the shape of oblate spheroids. The chief defect is a flattening of the front end which even becomes slightly indented at very high distortions. The major objection to the above-mentioned development is that the deviation from the spheroidal shape depends somewhat on the liquid involved. In view of the good correlation between Laws' and Watson's data, however, it is likely that this will not cause severe errors.

From these photographs, Henrickson obtained measurements of the lateral breadth, 2a, and the height, 2b, of the drops. The ratio, h = b/a, has been plotted in Figure 6, using drop diameter as a variable. Because measurements of drops 2 to 7 mm. in diam. could be made to an accuracy of only about ±0.1 mm., and oscillations were probably present, there is a considerable spread of the data points. Nevertheless, the trend is apparent and is well predicted by the lines calculated from Equation (30) and Table 1. No assumption of terminal velocity is necessary, so that these figures constitute a more reliable use of Henrickson's data than the y calculations.

Recalculation of Drag. Although the above-explained method provides a means of calculating the effect of distortion on drag. it is inconvenient to use. By calculating $c_D - Re$ curves for chosen values of the parameter Su, a direct plot is possible, as in Figure 1. Values used for the plot are tabulated in Table 2.

At terminal velocity it is more useful to replace c_D , Re, and Su by the following new groups:

$$= d \left[\frac{4}{3} \frac{g\rho_0 \mid \rho_i - \rho_0 \mid}{\mu_0^2} \right]^{b_0^*}$$

$$T_e = \frac{Re}{W!}$$

$$= V_t \left[\frac{3}{4} \frac{\rho_0^2}{g\mu_0 \mid \rho_i - \rho_0 \mid} \right]^{b_0^*}$$
(32)

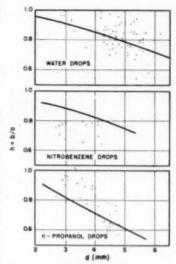


Fig. 6. Comparison of predicted and experimental distortions. Points represent date (13) for drops in air. Curves represent Equation (30) and Table 1.

$$Sd = \frac{Su}{Wt}$$

$$= \frac{g_c \sigma}{\mu_a} \left[\frac{3}{4} \frac{\rho_0^2}{g \mu_0 \mid \rho_1 - \rho_0 \mid} \right]^{1/2}$$
(33)

The parameter Sd is independent of both diameter and velocity, and is thus fixed for a given combination of phases. Calculated values are plotted in Figure 7, and tabulated in Table 3. The figure also includes Laws' and Watson's data, to show the agreement between experiments and predictions.

Oscillation of a Liquid Sphere. The distortion just correlated is merely the average value, about which the drop continuously oscillates. Some of these oscillations are started by the elongation which occurs when the drop breaks loose from the forming tip. Others result from the motion of the surrounding fluid, particularly in the wake, where

TABLE 2.—DRAG RELATIONS FOR DROPS

	DROLP	
Su	Re	e_{B}
104	200 250 300 400 500	.884 .883 .930 1.063 1.88
10s	500 800 800 1000 1300	.622 .600 .640 .741 1.072
100	1000 1200 1600 2000 2500 3000	.476 .469 .490 .543 .648

intermittent shedding of vortices probably occurs. Henrickson's (13) photographs of falling drops indicated the presence of oscillation even after falls of 20 ft. Williams (28) calculated the drag coefficients for Laws' data (17) on accelerating water drops. These show a definite oscillation. For each drop, the drag coefficient goes through three or four cycles during the observed fall. The magnitude of the effect indicates a variation of h, the fineness ratio, of about 0.1 each side of the equilibrium value.

In spite of these clear evidences of oscillation, the apparent success of the correlation based on average distortion shows that the oscillations do not severely influence the mechanics of motion of the drop. However, their effect on internal motion could be quite large, so that some consideration of the variables involved is justified.

Rayleigh (21) calculated the oscillatory motion of a liquid sphere. A complete derivation is given in Lamb (15). Considering only the most important mode, that representing motion between an oblate spheroid and a prolate spheroid, Rayleigh's equation can be written:

$$1 - \frac{2a}{d} = B \sin \left[8 \sqrt{\frac{g_e \sigma}{\rho_i d^2}} \theta + \phi \right]$$

$$= B \sin \left[8 \sqrt{\frac{\rho_i}{\rho_o}} \sqrt{SuTi} + \phi \right]$$
(34)

Here B is fractional amplitude and ϕ the phase angle of the sinusoidal oscillation.

In the absence of eddying within the drop, and neglecting any effect of the exterior fluid, the effect of liquid viscosity can be represented as:

$$B = B_o e^{-\frac{20\mu_i \theta}{\mu_i \theta^2}} = B_o e^{-20\frac{\mu_i}{\mu_o} Ti}$$
(35)

Here B_{ϕ} represents the initial fractional amplitude of the drop and is controlled by the formation or other shock which causes the oscillation. This equation shows that the amplitude of oscillation of a 3-mm, water drop decreases to about one half of its original value in 0.35 sec. or at a distance of fall from rest in air of about 60 cm.

The effect of eddying within the drop, if it were present, would be to increase the rate of energy dissipation, and therefore to increase the rate of amplitude decrease. The exact nature of this eddying is hard to predict.

Internal Motion Caused by Oscillation. This oscillating distortion is a source of internal circulation. For the case of streamline motion, the flow pattern can be calculated and is shown in

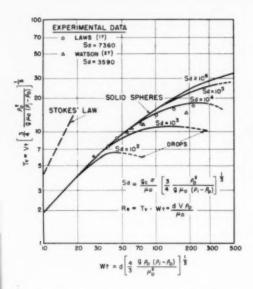


Fig. 7. Terminal velocities of spheres and drops.

Curves are based on Fig. 1, Equations (26), (27), (28), and (30), and Toble 1.

Figure 8a. The streamlines show that most of the motion occurs near the surtace. The maximum velocity, which occurs at the 45° latitude on the surface, is given by:

$$Rc_{i_m} = \frac{dV_{i_m}\rho_i}{\mu_i} = 3\sqrt{2\frac{\rho_i}{\rho_o}Su} \cdot \frac{\mu_o}{\mu_i}$$
(36)

 $V_{\rm im}$ is not the actual internal velocity, but merely the amplitude of this velocity. Velocities at other points are somewhat lower but are still appreciable. The Reynolds number obtained from Equation (36) for a water drop 3 mm. in diam. oscillating with a 5% amplitude

Fig. 8. Streamlines for internal motion. (Equidistant values of the stream function).

- (a) Oscillation with no internal eddies (15, p. 452)
- (b) Circulation in croeping motion with zero surface tension (15, p. 600).

(B=0.05) is 1100, so that V_{fin} is 37

Since these velocity amplitudes are proportional to the distortion amplitude, they also drop off exponentially with $(\mu_t/\mu_o)Ti$ when external forces are not acting. Their order of magnitude is given, in general, by

$$\sqrt{\frac{\mu_i}{\rho_o} Su \cdot \frac{\mu_o}{\mu_i} B}$$

which, even though it includes Su explicitly, may or may not depend on Su, since B is also a function of Su, ρ_k/ρ_o , and μ_o/μ_i , as well as of the tip or other cause of the oscillation.

Over and above this prediction of a sizable streamline velocity, there are the eddies which would undoubtedly form with such a nonlinear fluctuating flow when the amplitudes are as large as expected. These would probably

TABLE 3.-DRAG RELATIONS FOR

F-253541F2	DROPS	
S4	Wt	Tu
109	19.9 29.8 37.7 52.2	4.02 5.47 6.37 6.32
107	35.2 49.4 66.1 101.3 146.2	6.87 8.55 9.83 10.85 10.93 10.82
104	65.2 79.2 94.6 130 158 196 242 298	11.4 12.76 14.08 15.92 16.78 17.40 17.72 17.44
108	153.7 206 285 382 456	19.5 22.1 24.6 26.2 28.5

tend to distribute the motion more to the interior and away from the surface. However, the extent of this eddying should also depend on the groups $(\mu_4/\mu_0)Ti$ and $(\mu_4/\mu_0)(\mu_0/\mu_1)^2Su$.

Internal Circulation in Creeping Motion with No Surface Tension. The application of Stokes' method to "creeping" motion of a fluid sphere of zero surface tension was made by Rybczynski (23) and Hadamard (11). The derivation is given by Lamb (15). The result is similar to Stokes' law and can be written.

$$\frac{1}{k} \equiv \frac{V_t}{V_{t_d}} = \frac{24}{c_D R c} = \frac{1 + \mu_o/\mu_i}{1 + (2/3)(\mu_o/\mu_i)}$$
(37)

Streamlines for this motion are shown in Figure 8b. The maximum velocities occur at the origin and the equator and have the magnitude,

$$V_{4e} = \frac{V}{2(1 + \mu_o/\mu_4)}$$
 (38)

The minimum velocity, zero, occurs at the poles and on the equatorial plane where $r = d/2\sqrt{2}$. The amount of circulation can be defined as the flow through this circle of zero velocity, which is

$$q_i = \frac{\pi d^2}{32} \frac{V}{(1 + \mu_o/\mu_i)}$$
 (39)

Application of normal values of velocities and viscosities to these equations shows that for a drop in a gas, the effect of circulation on the drag and terminal velocity is slight, even though the internal velocity is still quite appreciable, while, for a bubble, the effect on the drag is large. In the latter case, the effect is so large that the bubble has a practically new surface upon moving one diameter. The case of drops in liquids is intermediate in both respects.

In a recent article, Kronig and Brink (14) calculate the effect of this circulation on mass transfer by diffusion. For the maximum circulation possible, the time required to reach a given average concentration is about 40% of that required in a stagnant drop.

Effect of Surface Tension on Internal Circulation in Stokes' Law Region. Unfortunately, this picture is too simplified even for the Stokes' law region since the actual boundary conditions must take account of the finite shearing stress supported by the surface tension of any actual system. This was first observed by Bond (6). In a series of experiments designed to test the validity of the above equation, he measured the terminal velocities of small bubbles and drops in very viscous fluids, so that creeping motion occurred, and the k of Equation (37) had a value of

2/3. Although a good many systems were found to obey Equation (37), certain anomalies were observed in some of the systems studied.

This anomalous behavior was further studied by Bond and Newton (7). By dimensional analysis, they obtained, for terminal velocity conditions, in place of Equation (37).

$$k = \phi \left(\frac{\mu_0}{\mu_i}, \frac{gd^2 \mid \rho_i - \rho_0 \mid}{g_c \sigma} \right) (40)$$

Here the latter group represents the ratio of the gravitational force, which at terminal velocity equals the drag, to the surface force. At low values of this group, k should be unity since the drop behaves as a solid sphere while, at high values, k should be given by Equation (37), since surface forces are negligible. Bond and Newton reasoned that the transition should occur where this second group was near unity. Actually, since only the skin friction is significant in causing the circulation, the critical diameter, do, should correspond to the point where the skin friction equals vogede or, since two thirds of the drag is skin friction in creeping motion,

$$\frac{2}{3} \frac{\pi}{6} g d_c^3 |\rho_i - \rho_o| = \pi g_c \sigma d_c$$

or

$$d_c = 3 \sqrt{\frac{g_c \sigma}{g \mid \rho_i - \rho_o \mid}}$$
 (41)

Bond and Newton's data show that the transition begins where d is about $0.1d_c$, and, in all cases, is completed when $d = d_c$. Thus the circulation becomes appreciable whenever the skin friction is a major portion of the surface forces.

At first glance the introduction of the surface tension as a variable in this manner seems questionable. There is no change in total area of the drop and, therefore, no change in the total surface energy. Nevertheless, there is a creation of surface at the front of the drop, and. as a result, a local creation of surface energy. If the internal fluid were completely nonviscous and this circulation once began, it could continue. The necessary energy at the front of the drop would be supplied by moving internal fluid, activated by the energy obtained by the loss of surface at the back of the drop. For a fluid with any viscosity, some of this energy would be lost in the motion. As a result, the circulation would soon damp out.

The action of the skin friction is to provide the energy to overcome this viscous damping. Even for low values of skin friction, a slow circulation could be maintained. However, the circulation should only become extensive when the skin friction is large enough to provide all of the energy necessary to form the surface at the front, with no necessary.

sity for transmitting energy through the internal fluid.

Extension of Circulation Criterion to Higher Reynolds Numbers. An extension to the region of higher Reynolds numbers can be made by assuming that the critical condition is the balance between skin friction and wog.d. Application of this leads to the conclusions that bubbles of gas in liquids are nearly always circulating, drops in gases are rarely circulating, and drops in liquids are usually in the transition region. Unfortunately, the direct experimental determination of circulation is difficult if not impossible in the higher Reynolds number range, and indirect determinations by way of mass transfer, etc., have not yet been well evaluated. However, mass-transfer studies by Hagerty (12) have clearly shown that bubbles do not normally have a liquid film surrounding them, and thus are probably circulating, as predicted by the equations shown.

Sample Problem

IT IS proposed to remove a small percentage of volatile solvent from a nonvolatile liquid by spraying countercurrent to a stream of nitrogen at atmospheric pressure and 300° F. The maximum available gas flow rate of 5000 actual cu.ft./min. is to be used to promote rapid mass transfer. The resulting dilution of the vapor is sufficient to make gas side mass-transfer resistance negligible, but liquid-phase diffusivity is so low that internal motion of the liquid is required. Nozzles available can create sprays with mean drop diameters between 0.1 and 7 mm. For proper spacing of the sprays, a cross-sectional area of at least 12 sq.ft. is needed. Fluid properties

gas density
gas viscosity
liquid density
liquid viscosity
surface tension
18 dynes/cm.

0.808 g./l.
0.023 cp.
65 lb./cu.ft. = 1.041 g./cc.

Evaluate this proposal in the light of the mechanics of drops as a preliminary to mass-transfer calculations.

Solution

 As a preliminary, the following groups are evaluated:

54 =

$$\frac{1(18)}{2.3 \times 10^{-4}} \left[\frac{3}{4} - \frac{(0.808)^8 10^{-8}}{980(2.3)10^{-4}(1.040)} \right]^{\frac{1}{2}}$$
= 1001

$$\frac{Tv}{V_t} = \left[\frac{3}{4} \frac{(0.808)^8 10^{-4}}{980(2.3)10^{-4}(1.040)} \right]^{1_0} 30.48$$
= 0.390 sec./ft.

$$\frac{W_t}{d} = \left[\frac{4}{3} \frac{980(0.808)10^{-4}(1.040)}{(2.3)^8 10^{-6}} \right]^{4/6} 10^{-1}$$

Thus, for several characteristic drop sizes:

Tv = 0.315 2.1 6.4 11.0 11.0 $V_1 = 0.808$ 5.38 16.42 28.2 28.2 ft./sec

(The 0.1 mm, case was evaluated from Stokes' law, in the form;

$$Tv = Wt^{2}/24$$

3 From the problem, the maximum superficial velocity is seen to be

$$u = (5000/60)/12 = 6.95$$
 ft./sec.

If this superficial velocity is used, the drops must all be larger than the size with a terminal velocity of 6.95 ft./sec., calculated as follows:

$$Tv = (0.390)(6.95) = 2.71$$

From Figure 7,

$$Wt = 14$$
; $\therefore d = 14/27.5 = 0.51$ mm.

 Some idea of whether skin friction causes any circulation can be obtained by evaluating the critical diameter, de, given by

$$\pi g_s a d_s = f \frac{\rho_s V_s^2}{2} \pi d_s^2$$

f, the friction factor, can be estimated as 2/√Re, for a sphere. It is expected that even though distortion slows down the drop, it increases circulation by increasing local values of shear stress. From these relations,

$$Wt_*Tv^0 = Sd^0 = 1.002 \times 10^6$$

From Figure 7 (using the sphere line) W₁, = 150; ∴ d_r = 150/27.5 = 5.45 mm. Thus, by extrapolating Bond and Newton's data, circulation is missing for drops smaller than 0.545 mm. and completely established for drops larger than 5.45 mm. Some idea of the extent of circulation is obtained by evaluating the circulation velocity, by Equation (38), and the period of circulation θ_θ = π_θ²/6q_θ, by Equation (39). These equations are for the Stokes' law region but will

be extrapolated here for want of another

$$d = 3$$
 7 mm,
 $V_{t_c} = 0.16$ 0.16 ft./sec.
 $\theta_c = 0.1635$ 0.382 sec.
 $\theta_c V_t = 4.61$ 10.78 ft.

The last row shows that the drops must fall several feet with respect to the gas to average one complete cycle of internal circulation. This will aid in transfer, but not strongly.

 A more promising possibility is oscillation. Typical initial oscillations are 50% of the drop diameter. Thus, from Equation (36).

$$V_{\text{lm}} = \frac{1}{30.48} \frac{0.020}{(1.041) \cdot 0.1d} \cdot 3 \left[\sqrt{2 \frac{1.041}{(0.808) \cdot 10^{-8}} \cdot 1001 \cdot (27.5) d} \right] \frac{0.023}{2} \cdot 0.5 = 0.915 / \sqrt{d} \text{ ft./sec.}$$

Thus, fo

equation:

$$d = 3$$
 7 mm. $V_{i_m} = 0.528$ 0.346 ft./sec.

These are somewhat higher than the corresponding circulation values. However, these oscillations decay. Equation (35) allows an estimation of the time required to damp to the same velocity maximum as for circulation. For

$$B/B_o = V_{f_c}/V_{f_m} = .303$$
 7 mm.

$$-ln\ B/B_* = 1.195$$
 0.771
 $\theta = 0.28$ 0.983 sec.
 $V_1\theta = 7.9$ 27.8 ft.
 $(V_1 - u)\theta = 6.0$ 20.9 ft.

The last row shows that a column taller than 6 ft. for 3-mm. drops and 20 ft. for 7-mm. drops is not desirable, since the additional height does not improve mass transfer because of low internal motion. A better alternative is collection and redispersion to make use of the formation transfer and start violent drop oscillations.

In this problem, heights have been calculated assuming terminal velocity with respect to the gas. This assumes the liquid leaves the nozzle at high velocity. Some estimate of acceleration effects can be made for zero nozzle velocity, however. For the 7-mm, drop,

$$Re_t = TvWt = 11(192.5) = 2220$$

 $c_D = Wt/Tv^2 = 192.5/(11)^3 = 1.59$

From Figure 4, by extrapolation,

$$b_{av}/m = 0.9$$

$$\therefore 1.9 \frac{dV}{d\theta} = g \left(1 - \frac{\rho_v}{\rho_z}\right) - 1.59 \frac{\rho_v V^2}{2\rho_z} \frac{3}{2d}$$

$$\frac{dV}{d\theta} = 16.93 - 0.0212 V^2$$

$$\therefore \theta = \int_{1}^{2\pi} \frac{dV}{16.93 - 0.0212 V^2}$$

$$\therefore \theta = \int_{e}^{aV} \frac{aV}{16.93 - 0.0212 \ V}$$
$$= 0.835 \ln \frac{28.2 + V}{28.2 - V}$$

and

$$\dot{h} = \int_{s}^{p} \frac{(V - n) dV}{16.93 - 0.0212 V^{2}}$$

$$= -23.6 \ln \left[1 - \left(\frac{V}{28.2} \right)^{2} \right]$$

$$- 10.835 \ln \left(\frac{28.2 + V}{28.2 - V} \right)$$

for

$$V = 5$$
 10
 $\theta = 0.30$ 0.62
 $h + \omega \theta = 0.753$ 3.18
 $h = -0.332$ -1.13
 $h/(V_t - u) = \cdots$

Comparison of the last row with the actual time, o, shows the error in neglecting acceleration time, when initial velocity is not close to the terminal ve-

From the above calculations, some idea of the internal motion of the various drop sizes is obtained. With this as a basis, mass-transfer calculations using either diffusion in a stagnant sphere, Kronig and Brink's method (14) for internal circulation, or some semiquanti-tative allowance for oscillation, will show whether or not increased surface per volume ratio of smaller drops outweighs their smaller internal motion.

Notation

A = Helmholtz free energy or work function

o = radius at the equator of a spheroid

Ac = acceleration group, Eq. (7) B = fractional amplitude of oscillation

 $B_o = \text{value of } B \text{ at } \theta = 0$

b =one-half the axis length of a spheroid

b =the "carried" mass

 $c_D = \text{drag coefficient, Eq. (1)}$

 c_{D_0} = value of c_D for steady state

= value of c_D for a sphere $c_D' = drag$ coefficient, based on true frontal area

 $c_{D}^{\prime D}$ = value of c_{D}^{\prime} for a disk d = diameter of a sphere of vol-

ume equal to the drop $d_o =$ value of d near circulation

transition, Eq. (41) e = eccentricity of a spheroid, Eq. (17)

g = acceleration of gravity

 $g_o = \text{conversion factor}, \frac{m_L}{F\theta^2}$

h = fineness of a spheroid = b/a

 $k = V_{t_0}/V_t$ for a circulating drop

m = mass of the drop or particle p_i = static pressure within drop

po = mean static pressure of surrounding fluid

 $p_n = local$ static pressure exerted on drop surface from with-

 $q = \text{function of } \rho_0/\rho_i$, Eq. (10)

 $q_i = internal$ circulation flow rate within drop

Re = Reynolds number based on equivalent sphere, Eq. (4) Re' = true Reynolds number, Eq.

(27) Re_{i_m} = Reynolds number amplitude for oscillation, Eq. (36)

S = surface area of drop

Su = surface tension group, Eq.(5)Sd = surface tension-size group, Eq. (33)

15	20	25	ft./sec.
0.99 7.87	1.48	2.32 36.6	ft
+0.99	6.25	20.5	ft.
0.0466	0.20.1	0.065	000

Ti = time group, Eq. (9)Tv = terminal velocity group, Eq.

(32)V =velocity of drop

v = drop volume

 $V_{4c} = \text{maximum internal circulation}$ velocity

Vim = maximum internal oscillation velocity

 $V_{a} = initial value of V$

 $V_t = \text{terminal velocity of drop}$

 V_{t_g} = value of V_t calculated from Stokes' law

W = work of distortion

Wt = gravity group, Eq. (6)

x,y,z = Cartesian coordinates using drop c.g. as origin and positive z axis as direction of motion

GREEK LETTERS:

 $\alpha,\beta = \text{functions of } \rho_0/\rho_i, \text{ Eq. (11)}$ and (12)

y = distortion coefficient, Eq.(24) $\theta = time$

 $\mu_i,\mu_o = \text{viscosity of inner and outer}$ phases

 $\rho_0, \rho_0 = \text{density of inner and outer}$ phases

 ρ_1,ρ_2 = radii of curvature at a given point on drop surface

 $\sigma = \text{surface or interfacial tension}$ χ = function defined in Eq. (8)

 ψ_1,ψ_2 = functions of h, Eq. (25) and (30)

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SATURATION PERFORMANCE OF ION-EXCHANGE AND ADSORPTION COLUMNS

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Regenerative operations in fixed beds are inherently more difficult to explain and calculate than the common steady-state counterflow operations, and a generally applicable method of analyzing them has not been available. The use of suitable dimensionless parameters makes it possible to represent the complete family of concentration-history curves, at any one value of an equilibrium parameter, as a contour plot in terms of a column-capacity parameter and a solution-capacity parameter.

Although analytic solutions are lacking for the differential equations representing the mass-transfer cases, numerical solutions for them are derived in this paper from H. C. Thomas's analytic results for the related reaction-rate-controlled case. Starting with a minimum of experimental data, these numerical solutions can be used by methods outlined here to predict column behavior over substantial ranges of operating conditions.

THE design of fixed-bed columns for adsorption operations, including ion exchange, is being given increasing attention in the chemical engineering literature. However, the theory of these operations is fragmentary and exists only as a series of special cases. Among the usable mathematical approaches to the problem, the method of Thomas (27, 28) has the greatest generality, because only this method takes into account the full range of possible variations in equilibrium constants for adsorption or exchange reactions.

Thomas's theory has escaped the use it deserves for several apparent reasons. First, it has involved the use of functions which have seemed difficult to evaluate. Second, it has been hased on a reaction-kinetic approach, and the relation of the known diffusional mechanisms to the kinetic framework has not been evident. Third, the mass-action equilibrium quotients are only roughly constant, particularly for adsorbents that are structurally inhomogeneous; and column adsorption is not strictly iso-

thermal. However, until such a time as exact solutions are found for the more complicated differential equations applying to the diffusional cases and to variable equilibria, the kinetic solution will remain a highly pseful and versatile method for interpretation and prediction of column performance. The present and succeeding papers will evaluate the Thomas solution and will utilize it for approximate solutions of the diffusional cases, to provide a unified theory for adsorption and ion-exchange operations in fixed-bed columns.

The nature of these operations will be reviewed briefly for purposes of definition. In simple fixed-bed adsorption, the solute undergoing adsorption is removed continually from the carrier liquid or gas and accumulates upon the surfaces of the solid phase. Such transfer proceeds until the concentration on the solid reaches a value corresponding to equilibrium with the concentration in the feed stream, and the column effluent reaches the feed concentration. Ion exchange is a case of exchange adsorption in which ions chemically bound in the resin phase are displaced in essentially stoichiometric proportions by ions initially in the liquid phase. In either adsorption or ion exchange, the step of accumulation in the solid phase is termed saturation. Likewise, the step in

the cyclic operation of a column in which the accumulated material is desorbed or displaced from the solid is known as elution or regeneration.

In a typical saturation operation, the column effluent is practically free of solute until a state of complete saturation of the entire column is approached. From then on, the effluent concentration increases rapidly toward the original feed concentration. The solute concentration in the effluent may be plotted against the cumulative volume V (or against the elapsed time +); such a plot is termed the concentration history for the adsorption or exchange. The point in the concentration history at which solute concentration just reaches a detectable level is known as the breakthrough volume or break-through time, and its exact location evidently depends upon the precision of the chemical analyses. That portion of the effluent concentration history in which the solute concentration increases from breakthrough to nearly complete saturation has been termed the break-through curve, the leakage curve, the adsorption wave (19), or the exchange zone (22). This region is of major practical importance, and the ensuing derivations will he carried out in order especially to calculate this portion of the entire concentration history.

Method of Second-order Kinetics

The kinetic derivation will be outlined briefly, using a practical and self-consistent nomenclature, so that a basis for comparison with the diffusional results can be provided.

The following type reactions for ion exchange and for physical adsorption will be considered:

$$A^{a+} + B \cdot \text{Resin} \rightarrow B^{a+} + A \cdot \text{Resin}$$

 $A + \text{Sorbent} \rightarrow A \cdot \text{Sorbent}$

The rate for ion exchange at the particle surfaces, in the case of ions of the same valence, may be expressed:

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Supplementary data (including tabular matter and figures are on file (Document 3665) with the American Documentation Institute, 1719 N Street, N.W., Washington, D. C. Obtainable by remitting \$1.00 for microfilm and \$4.80 for photocopies.

$$d(A \cdot \text{Resin})/d\tau$$

$$= k_{kin} [(A^{a+})(B \cdot \text{Resin})$$

$$-(1/K)(B^{a+})(A \cdot \text{Resin})] (1)$$

where the parentheses denote concentration, τ is the time variable, k_{kin} is the specific-rate factor for reaction in the forward direction, and K is the equilibrium constant for the reaction as written.

The following substitutions may then be made:

$$(A^{a+}) = c_A$$

 $(B^{a+}) = c_b - c_A$
 $(A \cdot \text{Resin}) = q_A$
 $(B \cdot \text{Resin}) = (Q - q_A) = (q_x - q_A)$

Here q_A is the amount, in gram-equivalents, of A combined per unit weight of dry resin; Q is the ultimate capacity of dry adsorbent, e.g., in gram-equivalents per unit weight; and q_x is the capacity of adsorbent that is reached at saturation. For ion exchange, only, $q_x = Q$. Some variation in Q with the feed concentration c_e may be observed (13): however, the equilibrium properties of the solid will be calculated on the basis of an appropriate constant value for the adsorbent capacity. Equation (1) then becomes:

$$\left(\frac{dq_A}{d\tau}\right)_{kin} = k_{kin} \left[c_A(q_x - q_A) - (1/K)q_A(c_o - c_A)\right]$$

$$(2)$$

Assuming a "Langmuir" equilibrium under practically isothermal reaction conditions, the rate for adsorption at the solid surfaces may be written;

$$d(A \cdot \text{Sorbent})/d\tau = k_{kin}[(A) (\text{Sorbent})]$$
 $-(1/K^{ad}) (A \cdot \text{Sorbent})]$

Let

 $(A) = c_A$
 $(A \cdot \text{Sorbent}) = q_A$
 $(\text{Sorbent}) = O - q_A$

where the symbols have meanings similar to those in ion exchange. There is then obtained:

$$\left(\frac{dq_A}{d\tau}\right)_{k|n} = k_{kin}[c_A(Q - q_A) - (1/K^{ad})q_A]$$
(3)

It is of interest to calculate the concentration on the adsorbent, $q_{\rm so}$, that is reached at saturation (i.e., when it is in equilibrium with the concentration of adsorbate A in the feed entering the column). By setting $dq_{\rm A}/d\tau=0$ and $c_{\rm A}=c_{\rm o}$, there results:

$$q_{\infty} = \frac{K^{ad}c_{a}Q}{1 + K^{ad}c_{a}} \tag{4}$$

Equation (3) may then be rewritten in terms of the limiting concentration q_{∞} rather than in terms of Q:

$$\frac{d(q_A/q_x)}{d[k_{kin}(\{1/K^{ad}\} + c_o)\tau]}$$

$$= \frac{c_A}{c_o} - \left(\frac{K^{ad}c_o}{1 + K^{ad}c_o}\right) \frac{c_A}{c_o} \cdot \frac{q_A}{q_x}$$

$$- \left(\frac{1}{1 + K^{ad}c_o}\right) \frac{q_A}{q_a} \qquad (4)$$

Equations (2) and (5) may then be put into identical form by introducing the following dimensionless parameters or moduli:

For ion exchange,

r = 1/K, the equilibrium parameter

$$t = k_{kin}c_o\left(\tau - \frac{vf_B}{R}\right)$$
$$= k_{kin}c_o\frac{(V - vf_E)}{R}$$

the solution-capacity parameter.

(7)

For adsorption,

$$r^{ad} = \frac{1}{1 + K^{ad}c_0} = 1 - \frac{q_\infty}{Q}$$

the equilibrium parameter (8)

$$t^{ad} = k_{kin} \left(\frac{1}{K^{ad}} + c_o \right) \left(\tau - \frac{vf_E}{R} \right)$$

 $= k_{kin} \left(\frac{1}{K^{ad}} + c_o \right) \left(\frac{V - vf_E}{R} \right)$

the solution-capacity parameter

In column operation, τ is the time measured from the first entry of saturating fluid into the column. This time must be corrected by subtracting the time vf_E/R required to fill the column; where v is the bulk volume of the column under consideration, f_B is the fraction of external voids per unit volume of the adsorbent as packed, and R is the volumetric flow rate. Also, $V(=\tau R)$ is the total volume of feed that has entered

By use of Equation (4) for adsorption, and the relation $q_n = Q$ for ion exchange, Equations (7) and (9) both conform to a general definition of the solution-capacity parameter:

the column; vf_R is the void volume of the column; and $V - vf_R$ is the volume

of effluent from the column.

$$t = k_{kin}c_o \frac{Q}{q_a} \frac{(V - vf_B)}{R}$$
 (10)

A still more general equation for t, that will include both the kinetic definition and the diffusional definitions to be given later, is

$$t = \frac{R}{D_0} \cdot \frac{V - v f_B}{R} \tag{11}$$

where D_a is a limiting distribution coefficient (dimensionless) between fluid and resin:

$$D_0 = \frac{q_x \rho_b}{c_0 f_x} \tag{12}$$

and, for the kinetic case, κ and k_{kin} are related by:

$$k_{bin} \cdot \frac{Q}{q_a} = \frac{\kappa f_E}{q_a \rho_b}$$
 (13)

where ρ_b is the density of dry adsorbent as packed in the column.

With these substitutions, at any particular cross section corresponding to a bulk volume v upstream, Equations (2) and (5) become

$$\left[\frac{d(q_A/q_x)}{dt}\right]_e = \frac{c_A}{c_o} \left(1 - \frac{q_A}{q_w}\right) - r\frac{q_A}{q_w} \left(1 - \frac{c_A}{c_e}\right)$$
(14)

(The restriction of constant s, to be defined below, is equivalent to the restriction of constant v.)

It will be shown elsewhere that r for elution is the reciprocal of r for saturation. Thus, although only $r \le 1$ occurs in the saturation step of adsorption, $r \ge 1$ is always encountered in the complementary elution, and the solutions involving r < 1 and r > 1 are equally important. In ion exchange, r < 1 and r > 1 are equally probable.

Material-balance Relation. The conservation equation, for an infinitesimal thickness of bed at any given cross section, expresses the fact that any loss of component A from the solution flowing through the section must equal the gain of component A on the solid and in the solution at that section:

$$-\left(\frac{\partial c_A}{\partial v}\right)_v = \rho_b \left(\frac{\partial q_A}{\partial V}\right)_v + f_B \left(\frac{\partial c_A}{\partial V}\right)_v$$
(15)

It is now convenient to consider the volume of saturating solution that has flowed through this cross section, $V-vf_B$, as a variable replacing the feed volume V. By a fundamental property of partial derivatives,

$$-\left(\frac{\partial c_A}{\partial v}\right)_{V}$$

$$= f_{E} \left[\frac{\partial c_A}{\partial (V - vf_{E})}\right]_{V} - \left(\frac{\partial c_A}{\partial v}\right)_{V - vf_{E}}$$

$$= f_{E} \left(\frac{\partial c_A}{\partial V}\right)_{v} - \left(\frac{\partial c_A}{\partial v}\right)_{V - vf_{E}}$$
(16)

Hence, Equation (15) simplifies to

$$-\left(\frac{\partial c_A}{\partial v}\right)_{V-vf_E} = \rho_b \left(\frac{\partial q_A}{\partial V}\right)_v$$

$$= \rho_b \left[\frac{\partial q_A}{\partial (V-vf_E)}\right]_v \qquad (17)$$

It is then necessary to define a dimensionless group involving v, analogous to Hougen and Marshall's thickness modulus, that will be related simply to the parameter t. This column-capacity parameter, s, is defined as

$$s = \kappa c f_E / R$$
 (18)

By comparison with Equations (10) and (13), s is seen to be related to the solution-capacity parameter t as follows:

$$\frac{t}{s} = \frac{c_o(V - vf_E)}{q_x \rho_b v} = \frac{(V - vf_E)}{D_O vf_E}$$
(19)

where $c_o(V - vf_R)$ is the quantity of solute originally carried by the total effluent, and $q_x\rho_bv$ represents the quantity of solute held on the bed at saturation; thus their quotient is a simple stoichiometric ratio.

Equation (17) may then be transformed to a still simpler form;

$$-\left[\frac{\partial (c_A/c_o)}{\partial s}\right]_t = \left[\frac{\partial (q_A/q_x)}{\partial t}\right]_s$$
(20)

The rate and conservation equations together provide a sufficient description of the system to permit a mathematical solution.

Integrated Equations. In order to utilize Thomas's solutions for design calculations, two steps have been taken. The first has been to replace Thomas's four parameters by the present three dimensionless groups, which allows all solutions to be given in a single family of contour plots. The second step has been to express all the solutions in terms of a function J, for which both plots and calculation methods are available.

The specific form of the solution equation is, of course, dependent on the boundary conditions chosen. The pertinent boundaries are essentially the same for both adsorption and ion exchange and will be described in terms of the latter. At the entrance to a bed of $B \cdot Resin$ (i.e., at v = 0), A + in the solution is at its feed value, c_{θ} . Also, when the front of the saturating fluid

just reaches the end of the bed (i.e., at $V=vf_B$), no A^+ has yet had time to enter the resin at that cross section. In dimensionless terms, these boundaries can be expressed as follows:

At
$$s = 0$$
, $c_A/c_o = 1$ (21)

At
$$t = 0$$
, $q_A/q_\infty = 0$. (22)

The reader is referred to Thomas's paper (27) for the intervening steps in solving Equations (14) and (20). The resulting solutions are

$$\frac{c_A}{c_a} =$$

$$\frac{\boldsymbol{J}(rs,t)}{\boldsymbol{J}(rs,t) + e^{(r-1)(t-s)}[1 - \boldsymbol{J}(s,rt)]}$$

and

$$\frac{q_{\mathbf{A}}}{q_{\mathbf{w}}} = \frac{1 - \mathbf{J}(t, rs)}{\mathbf{J}(rs, t) + e^{(r-1)\cdot(t-s)}[1 - \mathbf{J}(s, rt)]}$$
(24)

where J is the function derived by Furnas and others (2, 11, 25) as the solution of the related two-parameter problem of fixed-bed heat transfer:

$$J(x, y) = 1 - \int_{a}^{s} e^{-y-\xi} I_{a}(2\sqrt{y\xi}) d\xi$$
(25)

$$J(x,y) \stackrel{!}{=} \frac{1}{2} \left\{ 1 - H(\sqrt{x} - \sqrt{y}) + \frac{e^{-(\sqrt{x} - \sqrt{y})^2}}{\sqrt{x}[\sqrt{y} + \sqrt[4]{xy}]} \right\}$$
(27)

where I_o is a modified Bessel function of the first kind. It is apparent that J(x,y) is related to Thomas's function q(x,y) in the following manner:

$$J(x, y) = 1 - e^{-y - s} \varphi(x, y)$$

accurate to within 1% when $\sqrt{xy} \ge 6$, where H denotes the error function, given for any number z by the equation:

 $J(y,x) = e^{-y-\varepsilon I_0}(2\sqrt{xy})$

Since $I_a(0) = 1$ it is apparent that

J(0,y) = 1

 $J(x.0) = e^{-s}$

It can also be shown that the upper

 $\lim J(x,y) = 0$

 $\lim J(x,y) = 1$

Comparable boundaries and limiting

Plots of Integrated Results. The

concentrations in the effluent solutions

are of greater practical interest than the

local concentrations within the solid.

This paper will therefore consider di-

rectly the numerical evaluation of only

 c_A/c_o . In the evaluation of Equation

(23) J(x,y) must be known very ac-

curately, especially when it is close to

zero or unity. The evaluation of J(x,y)

in the region of x and y less than 10

will be described elsewhere. In the

region where the variables of the argu-

ment are both greater than 10, use has

been made of an asymptotic expansion

due to Onsager and given by Thomas

(28) which reduces to:

properties can be shown to apply for

the more complicated c_A/c_o function.

limits of J are:

the lower boundaries of J(x,y) are

(26b)

(26c)

(26d)

(26c)

(26f)

$$\begin{split} H(z) &= crf(z) \\ &= (2/\sqrt{\pi}) \int_{a}^{z} e^{-\beta d\zeta} \quad (28) \end{split}$$

Substitution into Equation (23) gives

$$\frac{c_o}{c_A} - 1 = \frac{\sqrt{\pi} [1 - H(\sqrt{rt} - \sqrt{s})] e^{(\sqrt{rt} - \sqrt{s})^3} - 1/(\sqrt{rt} + \sqrt[4]{rst})}{\sqrt{\pi} [1 - H(\sqrt{rs} - \sqrt{t})] e^{(\sqrt{rt} - \sqrt{t})^2} + 1/(\sqrt{t} + \sqrt[4]{rst})}$$
(29)

J(x,y) is also related to Brinkley's function $g(\sqrt{x}, \sqrt{y})$ as follows (6):

$$J(x,y) = 1 - g(\sqrt{x}, \sqrt{y})$$

Another relation useful in the evaluation of J is

$$1 - J(x,y) =$$

This equation enables c_A/c_o to be evaluated in a straightforward manner for any specified r, s, and t, since the error functions and exponentials are tabulated with high accuracy (20,21). In the following cases, the labor of calculation can be reduced by further simplifying the result:

 If the absolute value of the argument (√x - √y) exceeds 7, the absolute value of the error function H differs

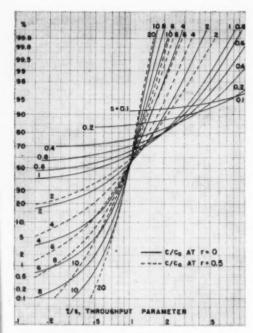


Fig. 1. Generalized break-through curves from kinetic solutions: c/c. vs. t/s, at r = 0 and 0.5.

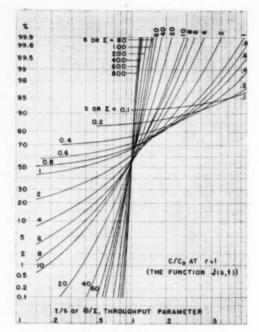


Fig. 2. Generalized break-through curves: c/c, vs. t/s or Θ/ϵ_r at r=1.

from unity by only a small amount, and approximations may be applied within 1% accuracy. Thus, ii

$$\begin{split} &(\sqrt{x}-\sqrt{y})>7\\ &\sqrt{\pi}[1-H(\sqrt{x}-\sqrt{y})]e^{(\sqrt{x}-\sqrt{y})^2}\\ &\doteq 1/(\sqrt{x}-\sqrt{y}) \end{split}$$
 or, if

$$(\sqrt{x} - \sqrt{y}) < -7$$

$$\sqrt{\pi} [1 - H(\sqrt{x} - \sqrt{y})] e^{(\sqrt{x} - \sqrt{y})^2}$$

$$\stackrel{\cdot}{=} 2\sqrt{\pi} e^{(\sqrt{x} - \sqrt{y})^2} \qquad (29b)$$

Either the numerator or the denominator of Equation (29), or in some cases both, may reduce by these means.

2. As r tends toward zero, and s and t are large enough so that $(\sqrt{rt} - \sqrt{s})$ and $(\sqrt{rs}-\sqrt{t})$ each become less than -7, Equation (29) becomes

$$\frac{c_e}{c_A} - 1 = e^{(\sqrt{rt} - \sqrt{s})^2 - (\sqrt{rs} - \sqrt{t})^2}$$

$$= e^{(r-1)(t-s)}$$
(30)

By a different derivation, the same result has been obtained by Sillén and Ekedahl (26) and (at r = 0) by Bohart and Adams (4),

3. If r becomes very large, so that $(\sqrt{rt} - \sqrt{s})$ and $(\sqrt{rs} - \sqrt{t})$ are each greater than +7, Equation (29a) can be used, and Equation (29) becomes

$$\frac{c_o}{c_A} - 1 = \frac{\sqrt{r} - \sqrt{t/s}}{(r\sqrt{t/s}) - \sqrt{r}}$$
(31)

This equation actually gives ca/c. as a function of t/s only and is thus independent of s.

It can also be proved that Equation (31) gives the equilibrium-limit behavior of c_4/c_0 . This is the behavior in a column that results from an infinite mass-transfer rate or from an infinitesimal flow rate. The proof involves use of Walter's result (30) for the equilibrium-limit behavior q_A/q_n at r > 1,

$$\frac{q_A}{q_a} = \frac{1}{r-1} \left(\sqrt{\frac{rt}{s}} - 1 \right) \quad (31a)$$

together with an equilibrium relation such as Equation (37), to obtain c_A/c_0 in the form given in Equation (31).

At all values of r, the equilibrium-limit curves are approached at all cases of high s, including also the case of a very long column. However, at r >> 1, the limiting curves are at r >> 1, the limiting curves are now proved to apply even under more readily attainable operating conditions. For $r \leq 1$, the equilibrium break-through curve is vertical at t = s; for r > 1, Equation (31) shows that equilibrium break-through begins at t = s/r and becomes complete at t = rs.

4. A second type of simplification is possible at particular values of t/s, which leads to rapid calculation of ca/co at these values and thus facilitates somewhat the construction of the entire c_s/c_o curve. The most useful singularities are those at t = s/r and t = rs, when r > 1. These singularities will fall respectively in the early and latter portions of the break-through curve. This new simplification may be used jointly with the pre-

At t = s/r, if $(r-1)\sqrt{t} > 7$, c_A/c_o is obtained in terms of constants and of Vs:

$$\frac{c_4}{c_0} = \frac{2r}{(r+1) + 2\sqrt{\pi s(r-1)}}$$
Likewise at (32)

Likewise, at

$$t = rs$$
, and $(r-1)\sqrt{s} > 7$.

there results

$$\frac{c_s}{c_s} = \frac{(r-1)(2\sqrt{\pi rs} + 1)}{2 + (r-1)(2\sqrt{\pi rs} + 1)}$$
(33)

Another such singularity occurs at t = s, and there Equation (31) is found to apply at relatively low values

By use of the methods just described, Equation (20) has been evaluated numerically for c/c, values between 0.001 and 0.999 at five separate values of r (0, 0.5, 1, 2, and 10) as a function of s (from 2 to 1000) and of t at necessary intervals. The results are given in Figures 1 to 3, as lines for c/co against t (actually, t/s) at constant values of column-capacity parameter s and at constant values of r.* Thus each curve corresponds to a concentration breakthrough for a particular column volume, flow rate, and exchange system. The ratio of t/s has been chosen as abscissa instead of t, primarily to give a more compact plot; t/s is given by Equation (19) and may be identified as a dimensionless throughput parameter.

The concentration histories as plotted against time on linear scales normally are S-shaped. The probability scale for e/c_o largely eliminates the curvature of such plots and also makes it possible to plot accurately those values that are either very small or very near to unity. The logarithmic scale for t/s (or for t) makes it possible to compare experimental e/c_o -time plots directly with the theoretical curves; this curve-fitting technique was utilized in analogous heat-transfer calculations by Furnas (11).

A family of curves similar to one of Figures 1, 2, and 3 should be constructed for the intermediate value of r that applies for the system under study. (If r is not known from other data, it can often be determined from column data by methods to be given in a later paper. This construction can be made by using a set of interpolative cross plots of either of the following types:

- A plot of c/c_o vs. r, at constant s, for a family of lines of constant t or constant t/s.
- A plot of t/s-1 (or another function of t) against r, at constant c/co, for lines of constant s. This type has

*Technichart No. 328, supplied by the Clearprint Paper Co., has been used for the logarithmic-probability plots of c/c.. To match experimental plots against the master solutions, the printed figures should be enlarged photostatically to 7.0 by 9.5 in. Alternatively, prints of this size can be made from the corresponding figures as included in A.D.I. microfilm, Document 3665.

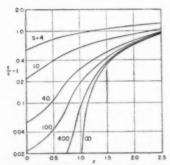


Fig. 4. Typical cross plot of throughput parameter values, at $\varepsilon/\varepsilon_\sigma=0.9$, against equilibrium parameter.

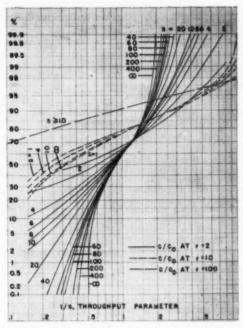


Fig. 3. Generalized break-through curves: c/c_r vs. t/s at r=2, 10, 100.

the advantage that fewer plots (each at a different c/c_o) are needed to represent the entire set of solutions. Such curves may be supplemented by plots of t/s - 1 against $s, ^*o$ at constant c/c_o , for lines of constant r, which allow interpolation to values of s not used in the previous set. These plots are shown schematically in Figures 4 and 5.

Mechanism and Rate of Molecular Transfer

The kinetic results just given provide a valuable pattern for identifying the significant variables in sorption operations, whatever their rate-determining mechanisms are. In this section it will be shown that the diffusional equations are closely related to the kinetic equations and that numerical results suitable for design calculations can be obtained by way of this close relation. As indicated by batch experiments (16), the diffusional mechanisms for ion exchange and for adsorption do not alter the basic nature of these operations as second-order-kinetic processes.

In both ion exchange and physical adsorption, the materials adsorbed upon the solid surfaces may be said either to

* Cross plots against both r and s have been prepared to represent solutions of Equation (23) at c/c_o values of 1, 10, 50, 90, and 99% and are available from A.D.I., Document 3665. have dissolved into the solid phase or to have undergone chemical reaction with it. The latter description is convenient and will be used even though it oversimplifies the physical situation. The sequence of molecular scale processes involved in ion exchange, i.e., in replacement of an ion A in the flowing fluid by another ion B originally on the solid, may be grouped into the following three steps:

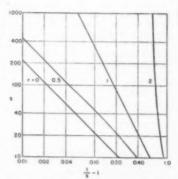


Fig. 5. Typical cross plot of throughput parameter values, at $c/c_{\rm c}=0.9$, against column-capacity parameter.

 External Diffusion. Counterdiffusion of A from the bulk fluid to the outer surface of the solid particle and of B from the particle to the bulk fluid.

from the particle to the bulk fluid.

2. Internal Diffusion. Counterdiffusion of A through the pores of the particle to the point where exchange occurs and of B from the exchange point back to the outer surface of the particle.

 Reaction. Desorption of B from the solid phase, and adsorption of A in its place.

Steps 1 and 2 respectively are sometimes called film diffusion (or F mechanism) and particle diffusion (or P mechanism) (5, 18).

If the solid is a homogeneous gel instead of a porous granule (3), or if diffusion in the solid phase is rapid compared to diffusion in the pore fluid, then reaction will occur at the outer surface of the particle, and steps 2 and 3 will be reversed in order.

In physical adsorption of a single component A, the same three steps will be involved, but each step will be unidirectional.

The effective rate of the adsorption or exchange will evidently be controlled mainly by the step that exerts the largest resistance to transfer and, therefore, inherently is slowest. The mathematical solution of the problem is simplified by neglecting all resistances but the rate-controlling one; or by combining all the steps into one effective step with a single apparent rate.

Surface-reaction Controlling. Reaction at the solid surfaces will be extremely rapid except in isolated cases of activated adsorption, and the resistance due to this step will generally be negligible. The theoretical importance of this case lies in the mathematical model that it provides for solving the diffusional cases.

External-diffusion Controlling. The rate of diffusion of solute between the bulk of the flowing fluid and the outer surfaces of the granules of adsorbent is evidently governed by the molecular or ionic diffusivity and also, in turbulent flow, by the eddy diffusivity which controls the effective thickness of the residual laminar-flow layer. Algebraically, for ion exchange,

$$\begin{split} \left(\frac{dq_A}{d\tau}\right)_{ext} &= (k_F)_A a_F \frac{f_E}{\rho_0} (c_A - c_A^*) \\ &= (k_F)_E a_F \frac{f_E}{\rho_0} (c_B^* - c_B) \end{split}$$

since equimolal counterdiffusion is approached. In Equation (34) the k_p 's are the mass-transfer coefficients, a_F is the transfer area per unit bulk volume, and c_A * and c_B * are the concentrations of A and B in the portion of fluid that is

adjacent to the outer surface of the solid (and thus is in equilibrium with it). As before,

$$c_A + c_B = c_o \tag{35}$$

Also,

$$c_A^* + c_B^* = c_o^* \stackrel{\cdot}{=} c_o$$
 (36)

The net rate of surface reaction given in Equation (2) may be set equal to zero, which yields the following equilibrium relation:

$$c_A^* = \frac{c_o^* q_A}{K q_x + (1 - K) q_A}$$
 (37)

As shown by Adamson and Grossman (1), Equations (35) to (37) will combine to give

$$\left(\frac{dq_A}{d\tau}\right)_{cxt} = \frac{(k_F)_A (k_F)_B d_F K f_E/\rho_b}{(k_F)_B K q_B + (k_F)_A q_A} \left[c_A (q_x - q_A) - rq_A (c_o - c_A)\right] \quad (38)$$

If $(k_F)_A$ and $(k_F)_B$ are approximately equal, both then may be replaced by their average, k_F , and Equation (38) reduces to:

$$\left(\frac{dq_A}{d\tau}\right)_{ext} = \frac{k_F a_F f_E/\rho_b}{q_x [1+(r-1)q_A/q_x]} \left[\varepsilon_A (q_x-q_A) - rq_A (\varepsilon_o-\varepsilon_A)\right] \ (39)$$

where r is defined by Equation (6). A similar derivation for simple adsorption leads exactly to Equation (39), if $r^{\rm od}$ is defined by Equation (8), and q_{∞} by Equation (4). An effective rate constant may be introduced by reference to Equation (13) and comparison of Equations (2) and (39), which enables Equation (23) to be used as the solution:

$$\frac{\kappa_{ext} f_E}{q_x \rho_b} = \frac{k_F a_F f_E}{q_x \rho_b [1 + (r-1) \left(q_A/q_a\right)]} \label{eq:kext}$$

$$\kappa_{ext} = \frac{k_F a_F}{1 + (r - 1) (q_A / q_{\varpi})}$$
 (40)

When the complete adsorption-wave curves are fitted, the average value of q_A/q_x may be taken as .5 if r < 1, or as 1/(r+1) if r > 1, as will be discussed in the section on constant-pattern curves;

$$\kappa_{ost} \doteq \frac{2k_F a_F}{r+1}$$
, if $r < 1$ (41)

$$\kappa_{ext} \doteq \frac{k_F a_F(r+1)}{2r}, \text{ if } r > 1$$
(41a)

The behavior of k_F in ion exchange is fully in agreement with other instances of mass transfer, including adsorption. Over a wide range of flow rates, $k_F a_F$ will vary inversely with $d_p^{1.6}$, as reported in a related paper (29). That reference provides a plot of $1.4(k_F S/R)$, which is labeled as an

adsorption group (sd_p/h) for the case of r=1 and is expressed as a function of d_pR/S (or, essentially, of the Reynolds number). When $r \neq 1$, the plot gives the group $(\mathbf{X}d_p/h)$, rather than (sd_p/h) . In this group, as will be explained following Equation (57), $\mathbf{X} = k_p a_p e f_E/R$ for external-diffusion controlling.

Internal-diffusion Controlling. The equations to be given are suitable for two types of internal diffusion. The first is the three-dimensional diffusion that will occur within a homogeneous gel-type particle; the 'second. indicated by Glucckauf (12), is two-dimensional diffusion (i.e., surface diffusion) along

pore boundaries, in case the particle consists of impervious crystallites

separated by pore spaces that are accessible to the solute.

A third case of internal diffusion may occur through the fluid phase contained in the pore spaces of a nonhomogeneous particle. If this type controls, reaction occurs subsequent to diffusion, just as in the external-diffusion-controlled case. Equation (39) then applies to fluid-phase internal diffusion with κ_p as transfer coefficient, while Equation (44) below applies to the two cases of solid-phase internal diffusion.

In all three cases, k_a or k_F' will be directly proportional to an appropriate diffusivity and inversely proportional to the mean width of the diffusional barrier. Generally, $k_a a_a$ or $k_{F'} a_{F'}$ will be inversely proportional to d_a^2 .

A general solution for the approach of a single adsorbent particle to a condition of saturation in a fixed bed has not yet been reported. A less exact treatment can be based upon the assumptions proposed by Glueckauf (12), Michaels (22), and others, in order to indicate qualitatively the relative effects of internal and external diffusion. In this treatment, the extent of saturation is averaged over the entire particle; and the rate of approach to complete saturation is taken to be proportional to the difference between the extent of saturation at the outer surface of the particle and the average extent of saturation within the particle. Thus, for ion exchange,

$$\left(\frac{dq_A}{d\tau}\right)_{solid} = k_P a_P (q_A^* - q_A)$$

$$= k_P a_P (q_B - q_B^*)$$
(42)

Here q_A and q_B are respectively the equivalent concentrations of A and B based on a unit weight of air-dried resin, a_P is the transfer area per unit volume for this case, and q_A * and q_B * are the local concentrations that prevail at the outer surface and are assumed to be in equilibrium with the fluid phase. The surface concentration of solute is therefore given by the following relation, derived from Equation (14) for a zero net rate of surface reaction:

$$q_A^* = \frac{q_x c_A}{(1-r)c_A + rc_o}$$
 (43)

Substitution of this relation into Equation (42) yields:

$$\left(\frac{dq_A}{dr}\right)_{mid} = \frac{k_F a_F}{(1-r)c_A + rc_o} \times \left[c_A(q_x - q_A) - rq_A(c_o - c_A)\right] \quad (44)$$

This equation, like the corresponding relation for external diffusion, applies equally well for simple adsorption. It will assume the form of the reaction-controlled case, Equation (14), if the following approximate substitution is made:

$$\begin{split} \kappa_{int} &= \frac{k_P a_P q_x \rho_b}{c_o f_E[(1-r)(c_A/c_o)_{av} + r]} \\ &= \frac{k_P a_P D_G}{(1-r)(c_A/c_o)_{av} + r} \end{split} \tag{45}$$

If the entire adsorption wave from $c_A=0$ to $c_A=c_0$ is of interest, then $0.5\ c_0$ is a permissible average value for c_A , and

$$\kappa_{int} \doteq \frac{2k_p a_p D_0}{(r+1)} \tag{46}$$

It is interesting to note that, for the hypothetical case where external diffusion and surface reaction occur in series at comparable rates, the resistances can be proved to be additive in a customary manner. The same additivity can be shown for resistances due to surface reaction and internal diffusion. From these two relations it can be inferred that the external and internal diffusional resistances also can be added in the following way:

† Since this paper was written, the authors have found that $(\phi q_A/\phi \tau) = k_P d_P \{(q_\Phi^*)^2 - q_\Phi^*\}/q_A$ provides a still better approximation for solid diffusion. However, no general solution has been found for the new equation, and it is less clearly related to the kinetic methods considered herein.

$$\frac{1}{\kappa} = \frac{1 + (r - 1)(q_A/q_{\infty})}{k_F a_F} + \frac{(1 - r)(c_A/c_o) + r}{k_F a_F D_Q}$$
(47)

or, from Equations (41) and (46), if $r \leq 1$.

$$\kappa \doteq \frac{2}{(r+1)\left(\frac{1}{k_F a_F} + \frac{1}{k_P a_P D_G}\right)}$$
(48)

Equation (48) indicates that external diffusion will control when $1/k_F a_F$ is larger than $1/k_P a_D O_D$, because of the then greater transport capacity of the solid phase. As $k_P a_P$ is always somewhat less than $k_F a_F$, internal diffusion is predicted to become the controlling resistance as D_O approaches 1, in agreement with experimental results (5).

The transition from external to internal diffusion has been observed experimentally by varying D_Q (i.e., by varying c_o) and also by varying k_F (by varying the flow rate). These data will be reported in a subsequent paper-

For adsorption in the diffusion-controlled cases it may be convenient to consider Q as an appropriate empirical constant rather than as an ultimate capacity in the Langmuir sense.

The present equations will then apply to any isotherm in which the curves of q^{*} (equilibrium q) vs. c are linear or concave downward at solution concentrations less than $c_{o^{*}}$ and can thus be fitted by proper adjustment of L and M in the relation:

$$q^* = \frac{Lc}{1 + Mc} \tag{4a}$$

In such a case Equation (4) becomes

$$q_a = \frac{Lc_a}{1 + Mc_a}$$
 (4b)

and Equation (8) takes the form:

$$r^{ad} = 1/(1 + Mc_a)$$
 (8a)

Equations (11), (12), and (18) still apply, along with the solutions based upon them. Hougen and Marshall's treatment of the linear isotherm for water on silica gel (14) is a special case of this generalized approach.

Exchanging Ions of Unequal Valence. The theories considered above are applicable to ion exchange only for cases where the exchanging ions have the same valence. Exact solutions are not known, in this more general case, for any of the proposed rate-controlling mechanisms. The chemical equation for this case is

$$A^{(a+)} + \frac{\alpha}{\beta} B \cdot \operatorname{Resin}_{\beta} \rightleftharpoons A \cdot \operatorname{Resin}_{\alpha}$$

$$+\frac{a}{B}B^{(B+)}$$

where α is the valence of ion A and β is the valence of ion B; α and β must have the same sign but may be either positive or negative.

The equilibrium expression for this exchange, as given by Bauman and Eichhorn (3), is:

$$K = \frac{(A \cdot \operatorname{Resin}_{\mathfrak{a}})^{\beta} (B^{(\beta+)})^{\mathfrak{a}}}{(B \cdot \operatorname{Resin}_{\beta})^{\mathfrak{a}} (A^{(\mathfrak{a}+)})^{\beta}}$$
(49)

In this equation the concentrations may be expressed in either moles or equivalents; because of the stoichiometry of the exchange, it is convenient to use equivalent concentrations and to designate them by c (for the solution) and q (for the resin) as before. Then

$$K = \frac{q_A \beta_{C_B} a}{q_B a_{C_A} \beta} \tag{50}$$

0

$$K\left(\frac{q_x}{c_o}\right)^{a-\beta} = \frac{(q_A/q_x)^{\beta}(c_B/c_o)^{\alpha}}{(q_B/q_x)^{\alpha}(c_A/c_o)^{\beta}}$$
(51)

For the case that $\beta = 1$, the surface-reaction-controlled rate may be written:

$$\left(\frac{d(q/q_x)}{d(K_{kin}q_x^{\alpha-1}c_o\tau)}\right)_{anf} = \frac{c_A}{c_o}\left(1 - \frac{q_A}{q_x}\right)^a$$

$$- \frac{c_o^{\alpha-1}}{Kq_x^{\alpha-1}} \frac{q_A}{q_x}\left(1 - \frac{c_A}{c_o}\right)^a (52)$$

DuDomaine, Hougen, and Swain (10) have solved this equation for the irreversible case where a=2 (bivalent-univalent exchange) and where $(Kq_{\pi}/c_0)>>1$.

For the external-diffusion-controlled case (with $\beta = 1$ and $\alpha \neq 1$), the rate is again given by Equation (34):

$$\begin{split} \left(\frac{dq}{d\tau}\right)_{cxt} &= k_F a_F (c_A - c_A^{\bullet}) \ f_B/\rho_b \\ &= k_F a_F (c_B^{\bullet} - c_B) f_E/\rho_b \end{split}$$

If Equation (50) is used to evaluate $c_A^{\ \ \phi}$, an irrational expression results which converts Equation (34) into an irrational form. A similar difficulty is encountered with the internal-diffusion-controlled case given in Equation (42).

A further approximation is therefore introduced, which involves replacing the true equilibrium by a second-order equilibrium. If $\beta = 1$, Equation (49) may be rewritten:

$$K\left(\frac{q_{\infty}}{c_o}\right)^{\alpha-1} = \frac{(q_A/q_o)(c_B/c_o)^{\alpha}}{(c_A/c_o)(q_B/q_o)^{\alpha}}$$
(53)

The apparent second-order equilibrium would have the form

$$K^{II} = \frac{1}{r} = \frac{(q_A/q_{\infty})(c_B/c_o)}{(c_A/c_o)(q_B/q_{\infty})}$$
(54)

In the vicinity of $(c_A/c_o) = 1$ and $(q_A/q_x) = 1$, $K^H = K^{1/a}(q_x/c_0)^{(a-1)/a}$. In the vicinity of $(c_B/c_o) = 1$ and $(q_B/q_x) = 1$, $K^{II} = K(q_x/c_o)^{a-1}$. A suitable average for purposes of approximation is given by

$$K^{II} = \frac{1}{r} = [K(q_a/c_o)^{a-1}]^{2/(a+1)}$$

(55)

The physical significance of this approximation is shown by Figure 6, in which the true and the approximate equilibria are plotted as calculated for a typical case where $\alpha = 2$ and Kq_x/c_0 = 30. It is seen that the general shape of the curves is much the same and that their intersection lies at $(c_A/c_o) = 1$ $-(q_A/q_{\infty})$. The numerical error in the approximate value of (q_A/q_{∞}) , for a given value of (c_A/c_o) , will decrease as $K(q_{\infty}/c_{\circ})^{\alpha-1}$ approaches unity. Confirmation of the method is provided by the unequal-valence data of Mongar and Wasserman (24), who found the experimental-rate constants to be essentially second order rather than third

This approximation, together with the use of gram-equivalent (or poundequivalent) concentrations, allows all the equations and plots presented for second-order exchange to be used also (with r calculated from K^{II}) for approximate correlations and predictions of the diffusion-controlled cases with unequal valence.

Number of Transfer Units. Parameters for Diffusion-controlled Cases. The total height of a column may be factored into the height per transfer unit H_T and the number of transfer units N_T :

$$h = N_T \cdot H_T \tag{56}$$

$$\frac{1}{(H_T)_F} = \frac{k_F a_F}{R/S f_E}$$
 (56a)

or

$$\frac{1}{(H_T)_P} = \frac{k_P a_P D_G}{R/S f_E} \qquad (56b)$$

as given by Chilton and Colburn (7). From this, for external-diffusion con- 'and the solution-capacity parameter is trolling.

$$(N_T)_F = \frac{h}{(H_T)_F} = k_F a_F \frac{v f_B}{R}$$

= $s[1 + (r - 1)(q_A/q_x)]$

(Kq. /c. -30) A' displacing B' (K" + 9.7) CA/CO

Fig. 6. Typical equilibrium distribution of ions between solution and resin, showing use of second-order constant (\mathbf{K}^{IJ}) to approximate the third-order values.

Similarly, for internal-diffusion controlling.

$$(N_T)_P = \frac{h}{(H_T)_P} = k_P a_P D_G \frac{v f_B}{R}$$

= $s[(1-r)(c_A/c_a) + r]$ (58)

For mass-transfer situations, the mathematical solutions for c/c_0 in terms of s and t are implicit, because s and t themselves involve either c/c_0 or q/q_∞ . As will be shown in the next section, the kinetic results can be used to construct approximate explicit solutions for the concentration histories as governed by mass transfer. In order to express these explicit solutions for c/c_o , new capacity parameters that depend only upon independent variables can be defined in terms of the number of transfer units. Thus, the column-capacity parameter for external-diffusion controlling is

$$\Sigma_F = (N_T)_F = k_F a_F v f_E / R \quad (59)$$

and the solution-capacity parameter for this case is

$$\Theta_F = \frac{(N_T)_F}{D_G} \cdot \frac{V - vf_E}{vf_E}$$

$$= \frac{k_F a_F}{D_G} \cdot \frac{V - vf_B}{R} \quad (59a)$$

Also, for internal diffusion controlling, the column-capacity parameter is

$$\Sigma_P = (N_T)_P = k_P a_P D_Q v f_E / R$$
(60)

$$\begin{aligned} & \Theta_P = (N_T)_P (V - v f_E) / v f_E \\ & \Theta_P = k_P a_P \frac{V - v f_E}{R} \end{aligned} \tag{60a}$$

The throughput parameter for the diffusional cases, Θ/Σ , is seen to be iden-

tical with t/s as previously defined (Equation (19)). Likewise, the equilibrium parameter r must be retained in unchanged form. In the event that r = 1, parameters Σ and Θ become identical with s and t respectively.

Thus, while parameters s and t are essential for obtaining numerical solutions of the differential equations, parameters \$\Sigma\$ and \$\textit{\textit{0}} likewise are necessary for using these solutions in the diffusion-controlled cases, as will be seen in the next section. The subscripts P and F are required on these parameters because the dependence of c/c_0 on Θ , at constant S, differs between the internaland the external-diffusion cases. In the transition region between these two cases, c/c_o must be calculated from the kinetic results by use of Equation (47) or (48)-

Numerical Solutions of the Diffusional Equations. The differential expressions for the diffusional rate, Equations (39) and (44), are seen to have the form of the kinetic-rate expression multiplied by a correction term. If the correction is practically constant, the kinetic solution may be applied directly in the diffusional cases.

If the correction factor is not constant over the entire break-through curve, the curve may be divided into several regions each of which is small enough for the correction factor to be essentially constant. In terms of curve-matching, this corresponds to matching different segments of a break-through curve to different kinetic curves; the kinetic s parameters for these different curves will all correspond to a single diffusional parameter S. However, this matching must be carried out on t/s plots, because only the t/s parameter is independent of the mechanism assumed.

To justify this matching, it is necessary to establish the identity of the slopes on the (t/s) and (Θ/Σ) plots. From Equation (20), the slope on a concentration-history plot is:

$$\begin{bmatrix}
\frac{\partial (c_A/c_o)}{\partial (t/s)} \end{bmatrix}_s \\
= \frac{1}{s} \begin{bmatrix}
\frac{\partial (q_A/q_x)}{\partial (t/s)} \end{bmatrix}_s \begin{bmatrix}
\frac{\partial s}{\partial (t/s)} \end{bmatrix}_{c/c_0} \\
(61)$$

From similar material-balance considerations, it can also be shown that:

$$\begin{split} & \left[\frac{\partial (c_A/c_o)}{\partial (\Theta/\Sigma)}\right]_{\Sigma} \\ &= \frac{1}{\Sigma} \left[\frac{\partial (q_A/q_w)}{\partial (\Theta/\Sigma)}\right]_{\Sigma} \left[\frac{\partial \Sigma}{\partial (\Theta/\Sigma)}\right]_{c/c_c} \\ &= \frac{1}{\Sigma} \left[\frac{\partial (q_A/q_w)}{\partial (t/s)}\right]_{\Sigma} \left[\frac{\partial \Sigma}{\partial (\Theta/\Sigma)}\right]_{c/c_o} \end{aligned} \tag{62}$$

The two slopes will be identical if $(1/s) \frac{\partial s}{\partial t} (t/s) = (1/\Sigma) \frac{\partial \Sigma}{\partial t} (\Theta/\Sigma)$

This equality follows readily from the definitions of Σ and Θ given in Equations (59) to (60a) and from the constancy or near constancy of the (s/Σ) ratio at a specified c_A/c_o .

Based upon the equivalence of slopes at related points or within related small increments of the kinetic and the diffusional curves, the following procedure was used in constructing the numerical plots of solutions of the diffusional equations and is recommended for any additional calculations of this type.

The over-all concentration range is divided into four segments, as follows:

ca/c. range, %	(ca/co) ong, %
1-10	3
10-50	30
50-90	70
90-99	97

At a given Σ , it is assumed that s is constant within each segment, as based upon the respective $(c_A/c_o)_{avp}$ or a corresponding $(q_A^*/q_w)_{avp}$. From a kinetic plot of c_A/c_o vs. t/s at the designated r, t/s is read at this s for the concentrations at each end of the range.

and a $\Delta(t/s)$ is computed and is taken equal to $\Delta(\Theta/\Sigma)$. The latter values are plotted consecutively on linear-coordinate paper, and the area between the break-through curve and $c_A/c_o=1$ is measured. A rectangle of unit height $(c_A/c_o)=1$ and equal area is drawn; if the left side is taken at $\Theta/\Sigma=0$, the right side gives the point of stoichiometric equivalence, $\Theta/\Sigma=1$. Location of the latter point establishes the absolute Θ/Σ coordinates of the entire curve.

The resulting curve for a constant Σ is then replotted on a probability-logarithmic scale to facilitate curve-matching. Curves can be extended beyond the limits of $1\% < (c_A/c_o) < 99\%$ by use of additional concentration ranges or by graphical extrapolation.

The kinetic and diffusional results become identical as r=1 and r>50; hence they deviate most widely from each other at 2 < r < 10 and at r=0. Exact relations are available for both the kinetic and the diffusional curves at r=0. Hence, in order to test the method in an extreme case, the external-diffusion curve at $\Sigma=60$ and r=0 was calculated directly by use of Equation (72) and indirectly by use of the foregoing procedure, starting with the kinetic relation (Equation (30) or

(68)). The results provide an excellent confirmation of the method:

ca/co, %	Θ/Σ by Eq. (72)	e/2 by stepwise calculation
1	0.9398	0.9400
10	0.9783	0.9786
50	1.0051	1.0046
90	1.0149	1.0156
90	1.0165	1.0168

Figures 7 and 8 present the curves calculated by the stepwise method. Figure 7 shows both external- and internal-diffusion curves at r = 0.5, and Figure 8 the corresponding curves at r = 2. It is seen that in the former case the external-diffusion curves are more concave upward and are below the internal-diffusion curves in the central range of concentrations, while in the latter case the reverse is true. Cross plots are presented * that permit rapid construction of either type of diffusional curve at any desired values of r and s within a wide range.

These curves are based upon the assumptions of constant effective diffusivity and constant equilibrium constant. However, the disadvantages

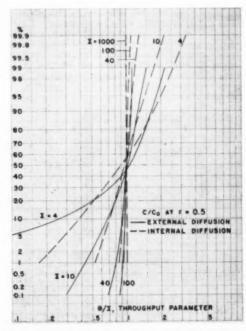


Fig. 7. Generalized break-through curves for diffusional cases; c/c_s vs. Θ/ϵ_r at r=0.5.

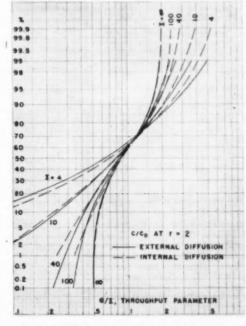


Fig. 8. Generalized break-through curves for diffusional cases: c/c_s vs. Θ/c_r at r=2.

^{*} See footnote, page 505.

attending these assumptions can be completely overcome, when necessary, by incorporating more accurate values of these variables into the computation of r and s values for each segment of a stepwise calculation. By such procedures, the kinetic curves provide a general path to numerical solutions for almost any definable case.

Specialized Solutions

The preceding equations and solutions contain those obtained by other investigators in several special cases and differ from them only in their greater generality and in the nomenclature used.

Linear-equilibrium Kinetics, Introduction of the condition that r = 1 will simplify the transfer equations and will make the diffusional equations identical in form with the kinetic one except for the constant-rate coefficient. For simple ion exchange, if r = 1, then K = 1; this situation rarely is realized exactly but often is approximated.* For adsorption, since $r = 1/(1 + K^{ad}c_a)$, the case of r = 1 applies to a wide range of adsorption conditions in which the equilibrium is highly unfavorable (i.e., Kadco<<1); this was realized by Wicke (31), Thomas (27), and Hougen and Marshall (14).

With r = 1, Equation (14) reduces

$$\left[\frac{\partial (q_A/q_x)}{\partial t}\right]_t = \frac{c_A}{c_a} - \frac{q_A}{q_x} \quad (63)$$

It is seen that the bimolecular rate is now described by an equation which effectively is first order rather than second order in the variables. Also, Equations (23) and (24) reduce to

$$c_A/c_a = J(s,t)$$
 (64)

$$q_A q_x = 1 - J(t,s)$$
. (65)

At large values of s and t, using Equations (27) and (64), or alternatively the approximation equations of Klinkenberg (17), there results:

$$c_A/c_b = \frac{1}{2}[1 + H(\sqrt{t} - \sqrt{s})]$$
(6)

with a maximum deviation of -0.02 at $s \ge 50$.

Constant-pattern or Constant-exchange-zone Case. It is an experimental fact that break-through curves are sometimes encountered which retain a constant shape on a linear time plot, subject only to a displacement in total clapsed time that is proportional to the total column length. When this occurs.

all parts of the exchange zone must move through the column at a constant rate; from stoichiometry, this rate of advance corresponds to the stipulation that $(\partial s/\partial t)_{\sigma_A/\sigma_0} = 1$ for each value of c_A/σ_0 and hence, by integration of Equation (17), that

$$\left(\frac{c_A}{c_o}\right)_{s,t} = \left(\frac{q_A}{q_x}\right)_{s,t}$$
 (67)

for the phases coexisting at any one point in the column. This was shown first by Wicke (31) and later by Sillén (24). It is theoretically possible for q_A/q_∞ to approach c_A/c_θ only when $r\leqslant 1$, because equilibrium restrictions prevent this approach if r>1. In actual practice the constant-exchange zone or constant pattern (so entitled by Michaels (22), and by Dryden (9), is encountered in relatively irreversible exchanges where r<<1.

The restriction of r<<1 leads to Equation (30), first derived by Sillén and Ekedahl, which is converted readily to logarithmic form:

$$\frac{1}{1-r} \ln \frac{c_o - c_A}{c_A} = s - t = t_{i_0} - t$$
(68)

where t_{0} is the particular value of the parameter t that corresponds to c_{A}/c_{0} = 0.5. In the t_{0} form this equation expresses the exchange-zone shape without regard to the upstream column volume. For s = 20 or above, this equation has a maximum deviation of only ± 0.01 even when r = 0.5. As $t_{0} \rightarrow \infty$, it will be noted that $t < t_{0}$ corresponds to $c_{A}/c_{0} = 0$ and $t > t_{0}$ corresponds to $c_{A}/c_{0} = 1$. Hence, with r < 1, the break-through curve in the equlibrium limit $(s \rightarrow \infty)$ will be vertical at an abscissa of t = s, as shown by Walter (30).

For any two fluid volumes U_1 and V_2 , utilizing Equation (68), Sillén and Ekedahl's result takes the alternate

$$\begin{split} \frac{1}{1-r} \ln \frac{c_{A2}(c_o - c_{A1})}{c_{A1}(c_o - c_{A2})} &= t_2 - t_1 \\ &= k_{kin} c_o \frac{Q}{q_x} \left(\frac{V_2 - V_1}{R}\right)_v \end{split}$$

This is analogous to the result of Michaels (22) for external-diffusion controlling:

$$\frac{1}{1-r}ln\frac{c_{A2}(c_o - c_{A1})}{c_{A1}(c_o - c_{A2})} + ln\frac{c_o - c_{A2}}{c_o - c_{A1}}$$

$$= k_F a_F \frac{f_E c_o}{\rho_0 q_E} \left(\frac{V_2 - V_1}{R}\right)_V$$

$$= (\Theta_F)_2 - (\Theta_F)_1 \qquad (70)$$

or to the result of Glueckauf and Coates

(12) for internal-diffusion controlling

$$\frac{r}{1-r} \ln \frac{c_{A2}(c_o - c_{A1})}{c_{A1}(c_o - c_{A2})} + \ln \frac{c_o - c_{A1}}{c_o - c_{A2}}$$

$$= k_p a_p \left(\frac{V_2 - V_1}{R}\right)_V$$

$$= (\Theta_P)_2 - (\Theta_P)_1 \tag{71}$$

If the adsorption exchange is completely irreversible (r = 0), then the external-diffusion equation takes essentially the form given by Drew, et al. (8):

$$\ln\frac{c_{A2}}{c_{A1}} = k_F a_F \frac{f_E c_o}{\rho_b q_\infty} \left(\frac{V_2 - V_1}{R}\right) \tag{72}$$

Michaels's and Glueckauf's relations were obtained by simple integration, because the approximation that $q_A/q_x = c_A/c_o$ enables the rate relation to be converted from a partial-differential equation to a total-differential equation that involves only c_A/c_o (or only q_A/q_x) but not both). The same technique has been applied by Glueckauf (12) and Johansson (15) to the case where a Freundlich isotherm is followed.

Monet (23) has pointed out that when internal and external diffusion occur at nearly comparable rates, the concentration history will reflect a transition from one mechanism to the other. The Sillén equation offers a good approximation for such situations and becomes exact (within the constant-exchange-zone restriction) in the event $k_F a_F = k_F a_P D_Q$.

The rate of advance of the adsorption wave assumes a particularly simple value under constant-pattern conditions. The ratio R_P of this rate (measured at a reference value of c/c_0) to the velocity of the fluid front is always

$$R_{F} = \left[\frac{\partial (v f_{E})}{\partial V}\right]_{e/e_{0}} \tag{73}$$

By introduction of Equation (19) in derivative form,

$$R_F = \frac{1}{1 + D_Q \left(\frac{\partial t}{\partial s}\right)_{c/c_Q}}$$
(74)

In the constant-pattern case, $(\partial t/\partial s)_{e/e_0}$ = 1, and there results

$$R_F = \frac{1}{1 + D_G}$$
 (75)

This is merely a restatement of the continuity condition and may be compared to a similar relation that applies to the center of gravity of chromatographic zones.

In summary, the concept of an exchange zone or adsorption wave of constant shape leads to very simple solutions in the nearly irreversible region from r = 0 to r = 0.5. With sufficiently

^{*} For binary-feed ion exchange involving trace concentrations, r also approaches unity, as is proved and utilized in a study of trace chromatography (29).

long residence times the constant-pattern method will be valid even at r=0.7 or r=0.8, but the numerical solutions obtainable from cross plots of Figures 1, 7, and 8 must be used to establish the range of validity.

Applications

Although adsorption or ion-exchange equipment of standard type is designed regularly on an empirical basis, specialized developmental problems arise repeatedly in which the first laboratory measurements may correspond to an uneconomic operation. Analysis of such problems by the present methods should provide a prediction, from minimum experimental data on a given ion-exchange or adsorption system, of the most efficient conditions under which that system may be operated.

The variables upon which the analysis depends are seen to be the ultimate adsorbent capacity Q, the solute concentration c_{θ} in the fluid phase, the rate R at which fluid is to be supplied, and the mass-transfer coefficients $(k_{p}a_{p})$ and $k_{p}a_{p}$, which include the effect of particle diameter and of flow rate and thus reflect the pressure drop that can be tolerated). The equilibrium constant K is fixed for any given solute and adsorbent: this, with c_{θ} and Q, determines the limiting-distribution coefficient D_{qp} .

The throughput time τ or volume V that is desired or permitted in each cycle of operation is a major independent variable. This, together with the column volume v, and the break-through concentration c_A/c_o then form a set of variables of which any one can be determined as a function of the other two.

Prediction of Concentration History from Known Mass-transfer Coefficients. For a column of given height, the smaller of the two Σ (or N_T) values will control, as calculated from general mass-transfer correlations for external diffusion or from known resin properties for internal diffusion. The concentration plots corresponding to the controlling mechanism must be used.

If the column volume, the volumetric flow rate, and the cycle period are all specified, the dimensionless parameters ∑ and ⊕ can be evaluated by Equations (59) to (60), and c_A/c_o can be read directly from charts such as Figures 1, 7, and 8 constructed for the value of r appropriate to the system. Assume, for example, that from other measurements for the ion pair and resin under study, kpap is found to be 20 min.-1 at a particular linear flow rate, and K = 2.0; also, $f_E = 0.4$, $\rho_b = 0.5$ g./ ml., and Q = 4.83 milliequiv./g. In addition, design values are specified for v = 75 ml., $c_0 = 0.6$ milliequiv./ml., and R = 30 ml./min. From this information

it follows that $D_G=10.1,\ r=0.5,\ {\rm and}\ \Sigma=40.$ If it is desired to calculate c_A at an effluent volume $(V-vf_B)$ of 264 ml., this corresponds to $\Theta=35,\ {\rm and}\ {\rm Figure}\ 7$ (for external diffusion) shows that at this Θ and $\Sigma,\ c_A/c_O=0.05,\ {\rm and}$ thus $c_A=0.03$ milliequiv./ml.

If the break-through value of c_A/c_o is specified, along with the column volume and (hence Σ), the value of Θ/Σ can be read from the appropriate chart, and, from this, τ or V can be calculated. By comparison with the previous example, assume that the given information leads to r=0.5, $\Sigma=40$, and $c_A/c_o=0.05$. Then Figure 6 shows that $\Theta/\Sigma=0.875$, so that $\Theta=35$, and $\tau=(\Theta/\Sigma)D_Gvf_B/R=8.8$ min.

If c_A/c_o and τ (hence Θ) are both specified, either a concentration plot having an expanded ordinate scale (Θ rather than Θ/Σ) can be used, or a cross plot giving Σ as a function of Θ at the particular r and c/c_o can be constructed rapidly from the data of the Θ/Σ charts.

Interpretation of Break-through Data. The available experimental data must be examined in order to analyze the mass-transfer behavior of the adsorption or ion-exchange system, before design calculations are made. If K is known for the system, reference curves of c/c_0 vs. Θ/Σ are constructed for the corresponding r, from the available cross plots. The experimental plot of c/c_o (preferably on a probability scale) against τ or V (on a logarithmic scale) is then matched to the family of reference curves to determine the applicable value of 2. If the experimental data provide the value of Θ/Σ , that is, of t/s as given in Equation (19), at a known c/c_a and a known r, Σ can be determined from a single measurement.

If r is not known from separate measurements, it can be estimated from a pair of saturation and elution runs at the same flow rate, or also sometimes from a set of saturation runs made under varied conditions. Methods for this purpose will be presented in a later paper, which will also show the excellent fit that the present solutions provide for experimental column-performance data.

Notation

A wide variation has been encountered in the nomenclature of previous workers. In this paper and a companion paper on chromatographic separations (29), the present authors have endeavored to assign the available Roman and Greek letters in a manner consistent with existing conventions. An effort has been made to select experimentally measurable quantities as the primary

variables. A table which compares the symbols used by different authors is included in the material filed with the A.D.I., and shows that a standard notation is greatly needed.

Dimensions of the variables are indicated in terms of a typical self-consistent set of units.

- a_F = effective area for mass transfer through fluid film surrounding adsorbent particles, sq-ft./cu. ft.
- a_n = effective area for mass transfer inside adsorbent particles, sq.ft./cu.ft.
- A, B, etc. = solute species
 - ad = superscript indicating a variable pertaining to a case of physical adsorption
- c_A, c_B, etc. = concentration of solute in a fluid phase at a specified point in the column, lb.moles (or lb.-equivalents)/cu.ft.
- c_A*, etc. = concentration of solute in the fluid phase, in equilibrium with the coexisting solid phase of concentration q_A, etc.
 - c_o = concentration of total solute in the fluid phase entering the column
 - D_q = ratio of concentrations on solid and in fluid phase at saturation, $q_a \rho_b / \epsilon_0 f_E$, dimensionless
 - $d_p = \text{mean diameter of adsorbent particles, ft.}$
 - f_E = ratio of void space outside particles of adsorbent to total volume of packed column, dimensionless
 - g = Brinkley's function, related to **J** [see Equation (26)], dimensionless
 - h = height or length of column.
 - H_T = height of a mass-transfer unit in the packed column, ft.
 - H = the error function,

$$(2/\sqrt{\pi})\int_0^x e^{-\zeta t}d\zeta$$

I_o = Bessel function of zero order and first kind, with imaginary argument.

$$I_o(2\sqrt{xy}) =$$

$$\sum_{m=0}^{\infty} (xy)m/(m!)^2$$

dimensionless

J =solution function giving c/c_o at r = 1, dimensionless

- kkin = rate factor for second-order surface-reactioncontrolled case, cu.ft./ lb.-mole/min.
- $k_P = \text{mass-transfer}$ coefficient for case of fluid-phase transfer controlling, ft.4 /lb./min.
- $k'_{F} =$ same as above, for case of pore-diffusion controlling
- $k_P = \text{mass-transfer}$ coefficient for case of transfer inside solid particles controlling, ft./min.
- K = chemical equilibrium constant for ion exchange, Kad = Langmuir constant for physical adsorption
- $K^{II} = apparent second-order$ equilibrium constant as approximated for exchanging ions of unequal valence, dimensionless
- L, M = numerical coefficients
 - $N_T =$ number of transfer units, as defined by Equation (57) or (58), dimensionless
- q_A,q_B , etc. = concentration of solute in the solid phase at a specified point in the column, lb.-moles (or lb.-equiv.)/lb. dry adsorbent
 - q_A^* , etc. = concentration of solute in the solid phase, in equilibrium with the coexisting liquid phase at concentration c_A , etc.
 - $q_* = \text{total}$ concentration of solute in the solid phase when complete saturation is reached. For ion exchange, $q_{\infty} = Q$; for simple adsorption, $q_x =$ $QKc_{o}/(1+Kc_{o})$, lb.-moles (or lb.-equiv.)/ lb. dry adsorbent
 - Q = ultimate adsorbent capacity of the solid phase, in concentration units
 - r = equilibrium parameter, dimensionless, for ion exchange, r = 1/K, for adsorption, r = 1/(1 +Kadco)
 - R = volumetric flow rate of fluid through fixed solid, cu.ft./min.
 - $R_F = \text{ratio of rate of zone ad-}$ vance to velocity of fluid, dimensionless
 - s = column-capacity parameter,dimensionless; $s = \kappa v f_R /$

- S = cross-sectional area of column, sq.ft.
- t = solution-capacity parameter for the kinetic case, dimensionless; $t = (\kappa / \epsilon)$ D_G) $(V - v f_E)/R$
- 1/s = throughput parameter, dimensionless; $t/s = c_0$ $(V-vf_B)/q_{\alpha}\rho_{\delta}v$ [see Equation (19)]
- U =actual linear flow rate of fluid phase through fixed solid, ft./min. Uf B is the superficial linear flow rate through an unpacked column of the same diameter
- v = bulk-packed volume of column, cu.ft.; v = hS; vf_R is the void volume of the column
- vpb = weight of dry adsorbent charged to column, lb.
 - V =volume of saturating fluid fed to column, cu.ft.; $V - v f_B$ is the volume of saturating fluid that has reached adsorbent at a volume v downstream from the column inlet
- x, y, z = variables
 - a = valence of ion A
 - β = valence of ion B; β may be equal to a
 - Δ = an increment, or difference $\zeta = a \text{ variable}$
 - $\kappa =$ general rate coefficient in the transfer-unit equations, 1/min. [see Equation (47)]
 - ρ_b = density of adsorbent, lb. (dry)/cu.ft. bulk volume (as packed in the column and saturated with carrier fluid)
 - $\xi = a$ variable associated with height or with column capacity
 - e == solution-capacity paramfor diffusional eter cases, dimensionless;
 - $(k_F a_F/D_G)(V v f_E/R)$

 - $k_P a_P (V v f_B) / R$
 - $\Theta/\Sigma = throughput$ parameter, same as t/s
 - **S** = column-capacity parameter for diffusional cases, dimensionless:
 - kpapuf R/R
 - OF
- kpap Douf #/R
- r = time, min.
- $\varphi = \text{Thomas's function } [cf.]$ Equation (26)]

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PRESSURE DROP IN ANNULI

Containing Transverse Fin Tubes

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Pressure drops for water flowing in annuli containing transverse fin tubes have been determined in the range of Reynolds numbers 260 to 63,000. For turbulent flow, maximum friction factors occurred when the fin spacing was four to five and one-half times the fin height. Friction factor plots are presented which may be used to predict friction factors in annuli containing transverse fin tubes. These plots were used to predict friction factors for helical fin tubes investigated by other workers and errors of $\pm 15\%$ in the predicted values were obtained in most cases.

THE purpose of the present investigation was to study the pressure drop for water flowing in annuli containing transverse fin tubes. Although empirical formulae for predicting pressure drops in annuli made up of two smooth tubes are quite well established, there is little information available which will allow the prediction of the pressure drop for fluids flowing parallel to transverse fin tubes.

The growing use of fin tubes in commercial heat-transfer equipment requires that some knowledge be available regarding the pressure-drop characteristics of fin tubes. In practice, flow parallel to transverse fin tubes is not ordinarily encountered. Such a type of flow, however, occurs to some extent in baffled multitube heat exchangers. Knowledge of pressure drops in annuli containing transverse fin tubes is the logical starting point for establishing relationships which will predict pressure drops in fin tube heat exchangers. Likewise, it has been shown recently that annuli containing transverse fin tubes have quite high heat-transfer capacity per unit of power expended in pumping the fluid through the annulus (6). Hence, knowledge of the pressure drop in such annuli would be useful.

Little work has been done on the pressure drop in annuli containing fin tubes. Such studies have been made by Gunter and Shaw (3), and de Lorenzo and Anderson (7), who studied longitudinal fin tubes. Annuli containing helical transverse fin tubes have been investigated by Katz, et al (5), Govier (2), and Knudsen and Katz (6). None of these latter investigations has been of sufficient extent to determine the effect of the variables involved in such annuli. Thus no empirical correlation showing the effect of fin spacing, fin height, inner-tube diameter, and outer-tube diameter has been obtained.

A cross section of an annulus containing a transverse fin tube is shown in Figure 1. Various dimensions which describe this annulus are the inside diameter of the outer tube, D_2 ; the fin diameter, D_1 ; the root diameter, D_a ; the fin height, W; the fin spacing, S; and the fin thickness, t. Some difficulty is encountered in selecting the appropriate equivalent diameter of an annulus containing a transverse fin tube. In irregular conduits the practice is to use an equivalent diameter which is four times the ratio of the cross-sectional area to the wetted perimeter. With amuli of the type considered in the present work, the cross-sectional area varies and the equivalent diameter obtained depends on the cross-sectional area used. Equation (1) expresses the equivalent diameter at the minimum cross section while Equation (1a) gives the equivalent diameter at the maximum cross section.

$$(D_B)_{min} = 4 \left[\frac{\pi (D_2^2 - D_1^2)}{4\pi (D_2 + D_1)} \right]$$

 $= D_2 - D_1$ (1)
 $(D_B)_{max} = 4 \left[\frac{\pi (D_2^2 - D_o^2)}{4\pi (D_2 - D_o)} \right]$
 $= D_2 - D_o$ (1a)

For irregular conduits a volumetric equivalent diameter has been developed which is four times the ratio of the free volume to the wetted surface. This equivalent diameter is used in correlat-

Complete detailed tables are on file (Document 3674) with the American Documentation Institute, 1719 N Street, N.W., Washington, D. C. Obtainable by remitting \$1.00 for microfilm and \$4.20 for photoprints.

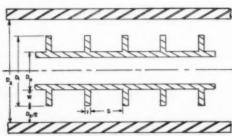


Fig. 1. Annulus containing a transverse fin tube.

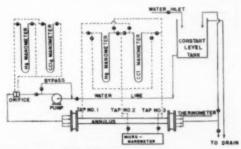


Fig. 2. Flow sheet of equipment.

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Fig. 3. Components of annulus.

ing data on banks of tubes. For the annuli containing transverse fin tubes the volumetric equivalent diameter is defined in Equation (2).

$$D_n =$$

volume of free space / foot annulus \ 4 area of wetted surface/ft. annulus

(2)

Jameson (4) has defined an equivalent diameter for transverse fin tubes. This equivalent diameter, expressed in Equation (3), is used to calculate the equivalent diameter of banks of transverse fin tubes

$$D_f = \frac{2[A_w + A_f]}{\pi p} \tag{3}$$

Using $(D_B)_{min}$ the Fanning friction factor may be calculated from Equation

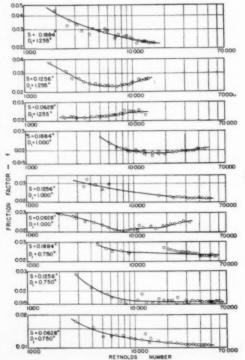


Fig. 4. Friction factors for various fin tubes.

TABLE 1 .- SUMMARY OF ISOTHERMAL PRESSURE-DROP DATA

	THE PERSON OF	TOO S SELECTION A SERVICE	SOURCE DATE	•
Fin Height in.	Fin Spacing in.	Reynolds Number range	Range of Water T * F.	No. of Tests
0.125	0.0628 0.1256 0.1884	2,760-48,800 2,350-60,000 2,850-63,500	58-69 60-68	29 23 38
4+	0.260	456-28,700 342-18,400	62-73 52-80 52-60	47
0.250	1.008 0.0628 0.1256	250-18,450 2,930-38,800 2,100-51,409	52-64 59-65 62-80	47 44 28 36
60	0.1884 0.260 0.504	6,090-45,000 260-23,000 236-18,800	60-78 51-66 52-62	30 45 36
60	1.003 1.507 2.006	261-13,500 249-18,700 321-19,700	52-60 52-61 51-60	50 36 38 80
0.377	0.0628 0.1256 0.1884	3,340-13,000 890-13,800 1,390-15,700	58-69 58-64 63-77	80 28 28 38
61	0.260 0.504 1.003	218- 9,450 201- 8,910 205- 7,300	52-68 52-63 52-64	38 36 37
41	1.507 2.006	235- 7.790 195- 8,020	52-70 52-61	38

* Reynolds number calculated from Equation (5) using $(D_B)_{min}$

$$\frac{-dP}{dL} = \frac{2fV^2\rho}{g_c(D_E)_{\min}} \tag{4}$$

Using this same equivalent diameter, the Revnolds number is

$$N_{Rs} = \frac{(D_E)_{min}V\rho}{\mu} \qquad (5)$$

If it is desired to calculate the Fanning friction factor and Reynolds number using a different equivalent diameter it is necessary only to substitute the required diameter in place of $(D_B)_{min}$ in Equations (4) and (5).

Knudsen and Katz (6) have found that for streamline flow in annuli containing helical transverse fin tubes, the friction-factor data for a number of different tubes could be satisfactorily correlated if the equivalent diameter $(D_R)_{min}$ was used. Using this equivalent diameter these workers reported turbulent flow friction factors for a number of helical transverse fin tubes. For each tube a separate friction factor-Reynolds number curve was obtained. Insufficient tubes were studied in order to obtain any empirical relationship which could be used to predict turbulent flow friction factors for helical transverse fin tubes in annuli.

Experimental Equipment

A schematic flow sheet of the experimental equipment is shown in Figure The outer pipe of the annulus consisted of two 52-in. lengths of cast Plexiglas tubing having an I.D. of 1.482 ± 0.005 in. Special entrance and exit sections similar to those used by Knudsen and Katz (6) were constructed. Pressure drops were determined over the downstream end of the annulus between taps numbers 2 and 3, which were 54 in. apart.

Transverse fin tubes were assembled using aluminum washers as fins with copper spacers between them on a $\frac{1}{2}$ -in. rod as illustrated in Figure 3. The copper spacers had an O.D. of 0.500 ± 0.002 in. Spacers Spacers having lengths of 0.0628, 0.260, 0.503, and 1.003 in. were made and using combinations of these, fin spacings of 0.0628, 0.1256,

0.1884, 0.260, 0.503, 1.003, 1.507, and 2.006 in. were investigated. Aluminum washers having diameters 0.750, 1.000, and 1.255 in. were used. With the above combination of fin spacings and fin diameters twenty-two different fin tubes were studied. The thickness of all the aluminum washers was 0.025 in.

All flow rates were determined by calibrated orifices. Pressure drops were determined by means of liquid-liquid differential manometers. In the case of small pressure drops a micromanometer was used.

Experimental Data

Isothermal pressure-drop data were obtained for water flowing in the annulus. A summary of the conditions for the measurement of the pressure drop

is given in Table 1. Twenty-two fintube arrangements were investigated. A complete tabulation of experimental data is too large for the present paper, but is available (1).*

Correlation of Experimental Data. As is shown in Table 1, a number of water flow rates were employed for each fin tube studied. The pressure drops obtained at these flow rates permitted the calculation of friction factors. Corresponding Reynolds numbers could also be calculated. All data were plotted in the form of friction factor-Reynolds number plots. It was found that an in-

* On deposit with the American Documentation Institute. dividual friction-factor curve was obtained for each of the twenty-two fin tubes studied regardless of which equivalent diameter was used to calculate the friction factor and the Reynolds number.

In Figures 4 and 5 all experimental data are shown plotted as the friction factor vs. the Reynolds number; these quantities were calculated using the equivalent diameter defined in Equation (1). These two figures show a total of twenty-two friction-factor curves, one for each fin tube studied. Figure 4 includes fin spacings of 0.0628, 0.1256, and 0.1884 in. and Figure 5 is for spacings of 0.260, 0.504, 1.003, 1.507, and 2.006 in. Both figures include the three different curves are the statement of the statement

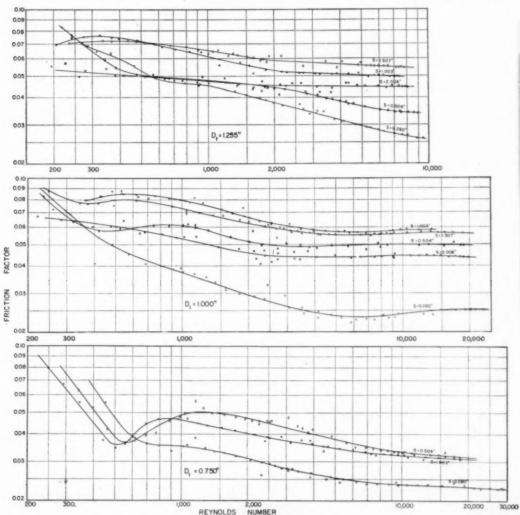


Fig. 5. Friction factors for various fin tubes.

ferent fin sizes studied. Experimental data are quite regular and in most cases deviate only a small amount from the drawn friction-factor curve.

Correlation of Streamline Flow Data. Figure 5 shows that in the region of low Reynolds numbers the friction factor is inversely proportional to the Reynolds number. The data, however, are limited in this region of flow. Based on these data the friction factors for streamline flow may be represented approximately by the following equations:

$$f = 21 N_{Re}^{-1}$$
 for $D_1 = 0.750$ in. (6)

$$f = 20 N_{Re}^{-1}$$
 for $D_1 = 1.000$ in.

$$f = 18 N_{Re}^{-1}$$
 for $D_1 = 1.255$ in. (8)

These equations may be averaged to the following:

$$f = 19.6 N_{Re}^{-1}$$
 (9)

This equation is only in fair agreement with that obtained by Knudsen and Katz (5) for streamlined flow over helical transverse fin tubes. These workers obtained the relationship

$$f = 24.6 N_{Re}^{-1}$$
 (10)

The reason for the discrepancy between Equations (9) and (10) may be due to a number of factors. Equation (9) is for true transverse fin tubes while Equation (10) is for helical fin tubes. An observational study of streamline flow over the helical fin tubes of low fin spacing (6) indicates that no liquid enters the fins spaces. Helical fin tubes should behave the same as true transverse fin tubes. The amount of streamline flow data obtained in the present work is not large enough to warrant a more general correlation than is given in Equations (6)-(8). It indicates, however, that the friction factor is inversely proportional to the Reynolds number.

Correlation of Turbulent-Flow Data. Figures 4 and 5 show that a friction-factor curve is obtained for each fin tube studied. In most cases, in the turbulent flow region, the friction factor decreases slightly as the Reynolds number increases and eventually becomes constant at high Reynolds numbers. In a few instances the friction factor has not reached a constant value and in still

other cases the friction factor actually increases with increasing Reynolds number. This latter phenomenon was also observed by Knudsen and Katz (6).

Figures 4 and 5 are of no use in predicting friction factors for annuli containing transverse fin tubes. A correlation is required which takes into account all the dimension variables describing the annulus. Dimensional analysis would indicate that the friction factor, in addition to being a function of the Reynolds number, is also a function of dimensionless ratios of the various length terms. In the present investigation, fin height and fin spacing are the only dimensions varied. Diameters D2 and Do remain constant. However, curves have been obtained which take into account all the significant dimensions of the annulus. Cross-plots have been made of Figures 4 and 5 at constant Reynolds numbers. These plots are the friction factor vs. the dimensionless ratio S/W, the fin spacing divided by the fin height. Figure 6 shows four such plots at Reynolds number values of 5,000, 10,000, 20,000, 50,000. Some extrapolation of the curves in Figures 4 and 5 is required to give all the curves in Figure 6. Each curve in Figure 6 is

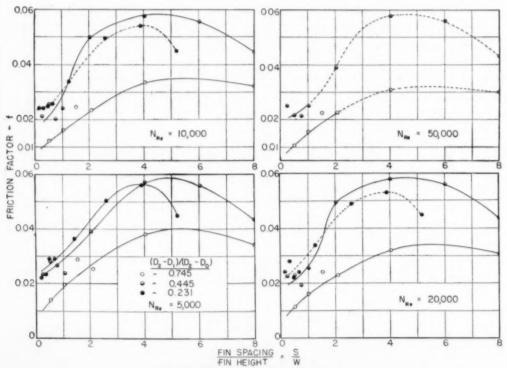


Fig. 6. Dimensionless friction factor plots for fin tubes.

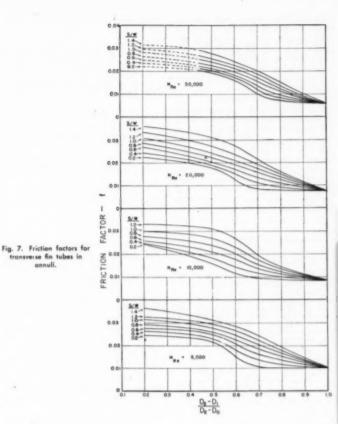
at a constant value of the dimensionless term, $(D_2 - D_1)/(D_2 - D_4)$. Hence, Figure 6 is a dimensionless plot and considers all length terms in the annulus except the fin thickness, which is constant at a value of 0.025 in. Inspection of Figure 6 shows considerable scattering of the points at low values of S/W. Smooth curves have been drawn through these scattered points.

In studying the friction-factor curves for one fin diameter, it is observed that in the turbulent flow region the friction factor increases with fin spacing up to a certain point and then decreases as fin spacing is further increased. One can look upon a fin tube as a rough tube whose roughness varies with the fin spacing. At zero fin spacing the tube is smooth and at infinite fin spacing the tube is also smooth. Somewhere between these two extremes the tube attains a maximum roughness. It is at this point of maximum roughness that the friction factor has its largest value.

Curves in Figure 6 all show maxima at certain values of the fin spacing to fin height ratio. These maxima indicate the point at which the fin tube is the roughest. In general, it may be concluded from Figure 6, that when the fin spacing is four to five and one-half times the fin height the friction factor will have its maximum value.

Figure 6 may be used directly to predict friction factors in annuli containing transverse fin tubes. For any given annulus and fin tube, the ratios S/W and $(D_2 - D_1)/(D_2 - D_0)$ may be easily calculated. By interpolation of the curves in Figure 6, the friction factor for the annulus in question is obtained at values of the Reynolds number of 5,000, 10,000, 20,000, and 50,000. A friction-factor curve then may be drawn.

A more useful series of plots is given in Figure 7 for low values of S/W. Plots in Figure 7 are cross-plots of Figure 6 and may also be used directly to predict the friction factor of any annulus containing a transverse fin tube. The series of plots in Figure 7 are somewhat similar to those given by Perry (8) for the prediction of friction factors for fluids flowing normal to banks of tubes. These curves in Figure 7 are a result of cross-plotting the friction factor-Reynolds number curves and of smoothing the data. The smoothed cross-plots, shown in Figure 6, deviate from the experimental data by a maximum of about 15% in some cases. Most points shown in Figure 6, however, lie on the curves. Predicted friction factors from Figure 7 will not differ more than 15% from experimental friction factors for true transverse fin tubes, the difference in most cases being much less. Although Figures 6 and 7 are dimensionless, they have been obtained for con-



stant values of D2, D6, and the fin thick-

annuli.

Use of Plots to Predict Friction Factors, Knudsen and Katz (6) have presented data on friction factors for

helical transverse fin tubes in annuli using different values of D2 and D0 from those in the present work. Plots in Figure 7 have been used to predict friction factors for the helical fin tubes

TABLE 2.—COMPARISON OF PREDICTED AND EXPERIMENTAL FRICTION FACTORS FOR HELICAL FIN TUBES

Tubes tested by K	nudsen and K	atz (f)					
Tube No. S/W	0.94	2 1.15	3 0.512	0.780	0.461	0.320	
$\frac{D_2 - D_1}{D_2 - D_s}$	0.975	0.735	0.748	0.618	0.577	0.570	
$N_{Bo} = 5,000$							
Predicted f (Fig. 7)	0.0125	0.0200	0.0140	0.0220	0.0220	0.0205	
Experimental /	0.0170 -36.5	0.0168 +19.0	$0.0160 \\ -12.5$	0.0218 +0.9	$0.0238 \\ -7.6$	$0.0262 \\ -21.4$	
$N_{Bs} = 10,000$							
Predicted f Experimental f % Error	0.0108 0.0110 -4.5	0.0165 0.0150 +10.0	0.0116 0.0135 -14.0	0.0180 0.0190 -8.2	0.0174 0.0225 -22.3	0.0160 0.0258 38.0	
$N_{Ba} = 20,000$							
Predicted f Experimental f % Error	0.0105 0.0092 +14.1	0.0155 0.0146 +6.2	0.0115 0.0118 -2.5	0.0180 0.0200 10.0	0.0171 0.0235 -27,2	0.0156 0.0265 -41.2	
$N_{Bo} = 50,000$							
Predicted f Experimental f % Error	0.0095 0.0072 + 83	0.0149 0.0139 +7.3	0.0105 0.0100 +5.0	0.0175 0.0195 10.2	0.0171 0.0230 -25.2	0.0163 0.0290 -44.0	

studied by these workers and these predicted friction factors are compared with experimental friction factors. These comparisons are shown in Table 2 along with the percentage error in the predicted value. The percentage error is calculated assuming the experimental friction factor to be correct.

Table 2 indicates agreement within ±15% between most predicted and experimental values of the friction factor for values of S/W from 0.5 to 1.2 and of $(D_2 - D_1)/(D_2 - D_0)$ between 0.6 and 1.0. For smaller values of these quantities the predicted friction factor may be in error by as much as 50%. Results in Table 2 are encouraging since the predicted friction factors apply to true transverse fin tubes and the experimental values are for helical fin tubes and were obtained for different values of Do and Do. The fins on the helical fin tubes studied by Knudsen and Katz were sufficiently close so they approximated true transverse fins.

Numerical Example. To illustrate the use of Figure 7 the friction factor will be determined for an annulus containing a fin tube with 6 fins/in. The fin thickness is 0.025 in. The diameter of the fins is 1.000 and the root diameter of the fin tube is 0.625 in. The outer tube of the annulus has an I.D. of 1.750 in. Summarizing the above data (in inches).

$$D_z = 1.750$$

 $D_3 = 1.000$
 $D_a = 0.625$
 $(D_S)_{min} = D_0 - D_1 = 0.750$
 $W = \frac{D_1 - D_n}{2} = 0.1875$

The fin spacing, S, is determined from the fins per inch and the fin thickness

$$S = \frac{1 - (0.025)(6)}{6} = 0.1417$$
 in.

Thus

$$\frac{S}{H^*} = \frac{0.1417}{0.1875} = 0.755$$

$$\frac{D_u - D_t}{D_0 - D_a} = \frac{0.750}{1.125} = 0.667$$

For S/W=0.755 and $(D_0-D_1)/(D_0-D_0)=0.667$ the friction factor at various Reynolds numbers is determined from Figure 7. These values for the friction factor are as follows:

Reynolds number	Friction factor			
5,000	0.019			
10,000	0.016			
20,000	0.016			
50,000	0.016			

A friction factor-Reynolds number curve may be drawn for the annulus under consideration, which curve may subsequently be used to calculate the pressure drop in the annulus at any flow rate for turbulent flow

It is desired to find the power required to overcome the friction in the above annulus, 10 ft. in length, in which water is flowing at the rate of 20 gal./min. The temperature is assumed to be 50° F.

Annular cross-sectional area outside of

 $= \pi/4(D_2^2 - D_1^2) = \pi/4(1.750^2 - 1.000^2)$ = 1.618 in."

Average lineal velocity in annulus

$$= \frac{(20)(144)}{(60)(7.48)(1.618)} = 3.97 \text{ ft./sec.}$$

Viscosity of water at 50° F. = 1.308 cp. From Equation (5)

$$N_{E_{\theta}} = \frac{(0.750)(3.97)(62.4)}{(12)(1.308)(0.000672)} = 17,700$$

For this Reynolds number f = 0.016. From Equation (4) $-\Delta P$ due to friction in 10 ft. of annulus is

$$-\Delta P = \frac{(2)(0.016)(3.97)^{2}(62.4)(12)(10)}{(32.2)(0.750)}$$

= 156 lb./sq.ft. = 1.08 lb./sq.in, Horsepower required to overcome friction

$$= \frac{156(20)}{(7.48)33,000} = 0.095 \text{ hp.}$$

Conclusions

Pressure drops have been determined for water flowing in annuli containing transverse fin tubes. The effect of varying the fin height and the fin spacing has been investigated, the root diameter of the fin tube and the inside diameter of the outer tube of the annulus being kept constant throughout all the tests. Twenty-two different fin tubes were studied, these tubes being made up of an assembly of aluminum fins separated by spacers mounted on a solid rod.

Limited data in the region of streamline flow indicate that the friction factor varies inversely as the Reynolds number.

Friction factors and Reynolds numbers were calculated using an equivalent diameter equal to $D_2 - D_1$. For each fin tube a separate friction factor-Reynolds number curve was obtained. A separate curve was also obtained for each tube when these quantities were calculated using other equivalent dia-

Results for the region of turbulent flow indicate that at a constant fin height, the friction factor for a fin tube increases with increasing fin spacing up to a certain point and then decreases as fin spacing is further increased. The maximum friction factor occurs when the fin spacing is four to five and onehalf times the fin height.

Curves are presented for determining the friction factor in any annulus. One set of curves is obtained at each Reynolds number and the dimensionless ratios S/W, the fin spacing divided by the fin height, and $(D_2 - D_1)/$ $(D_2 - D_0)$ are taken into account. In this way all length terms in the annulus, except the fin thickness, are involved. Figures 6 and 7 have been used to predict friction factors for helical fin tubes investigated by other workers and errors

of ±15% in the predicted value were obtained in most cases. The frictionfactor plots in Figures 6 and 7 are proposed for predicting friction factors in annuli containing transverse fin tubes.

Notation

 $A_t =$ fin area of transverse fin tube, sq.ft./ft.

 A_w = tube area of transverse fin tube, sq.ft./ft.

 $(D_E)_{max} = \text{equivalent}$ diameter at maximum cross section, Eq. (1)

 $(D_E)_{min} = equivalent$ diameter minimum cross section Eq. (1a)

 $D_f =$ equivalent diameter of fin tube, Eq. (3)

Do = volumetric equivalent diameter of annulus, ft., Eq. (2)

 D_2 = inside diameter of outside tube, ft. or in.

 $D_1 = \text{diameter of fins, ft. or in.}$ $D_a = \text{root diameter of fin tube,}$ ft. or in.

f = Fanning friction factor, dimensionless

 $g_o = \text{dimensional constant}, (lb.)$ (ft.)/(sec.)2(lb. force)

L = length along annulus, ft.N_{Re} = Reynolds number, dimensionless

-dP = pressure drop due to friction, lb./sq.ft.

p = projected perimeter of fin tube, ft./ft.

S =fin spacing, it. or in. t = thickness of fins, ft.

V = average lineal velocity in annular space, ft./sec.

W = height of fin. ft. or in. $\mu = \text{viscosity lb./(sec.)(ft.)}$ ρ = fluid density, lb./cu.ft.

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INDUSTRIAL VIEWPOINTS ON SEPARATION PROCESSES

PART I

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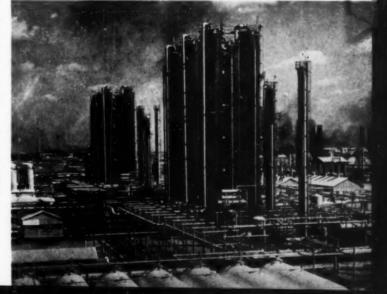
Separation processes, such as fractional distillation, solvent extraction, and others, are basically analogous. Industrial application of new separation processes to old separations or of familiar separation processes to new separations becomes much easier to visualize when the inherent similarities are realized. Certain criteria must be used and certain limitations are always present regardless of the separation process applied. This article reviews the principles of design and operation of separation processes from the viewpoint of industrial application. It gives a practical guide by which one may quickly estimate the ease or difficulty of a separation. It suggests methods for attacking difficult separation problems. A method is outlined for estimating the separation in a primary tower without requiring preliminary estimations of the effect of recycle streams from subsequent steps. A procedure is given for estimating nonideal, multicomponent phase equilibria from easily obtainable binary phase equilibria. Emphasis is placed on obtaining practical solutions to separation problems in a reasonable length of time. Where necessary, rigorous methods are used, but when such methods become unwieldy and time-consuming they are abandoned for approximations which serve practical purposes.

common of these processes are fractional distillation, solvent extraction, gas absorption, adsorption, and fractional crystallization. Most of the discussion here will pertain to the more "difficult" separations, that is separations requiring several to many equilibrium steps or mass-transfer units. Although there are no different problems involved in "easy" separations, such as recovery of salt from brine or sugar from molasses, the emphasis is different. There the emphasis is on the problem of transferring and using large quantities of heat cheaply. Much attention is directed toward controlling minor impurities while the main separation is treated somewhat incidentally. In difficult separations attention is directed toward the mechanism of the separation

S EPARATION is a most important industrial process. Such industries, as petroleum, petrochemical and the chemical industry in general, have large investments in separation equipment and spend much more in operation. Nature rarely provides a raw material in pure form and few conversion processes produce pure products. The more complicated our industrial economy becomes, the more different materials required in relatively pure form for feed stock, and the more finished products there are to be separated from by-products and impurities. Therefore, separation is a big business.

Definition. The separations considered here are those where molecular mixtures are separated into pure compounds or at least into two or more fractions having different compositions by processes sometimes classified by the term "diffusional operations." The more

Fig. 1. Fractional Distillation Towers and Auxiliaries.
Equipment situated in Plains butadiene plant owned by Reconstruction Finance Corp.



[†]Part I of a three-part paper. Part II will appear in an early issue.

transfer and minor impurity problems are there but their solution is secondary to that of the primary separation. Furthermore, the separations discussed will be continuous separations since most large-scale industrial applications are of this nature.

Basic Similarity of Separation Processes

A casual review of the separation processes listed will reveal certain typical similarities. For all practical purposes, two mechanically separable phases are handled in each process:

Fractional Distillation Extractive distillation Azeotropic distillation Gas absorption Oil stripping Solvent extraction Adsorption Vapor-liquid Vapor-liquid Vapor-liquid Vapor-liquid Liquid-liquid Vapor-solid Liquid-solid Liquid-solid

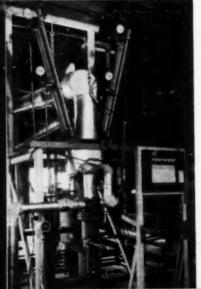
(The several gas and liquid diffusion separation processes where the two countercurrent streams are completely miscible were not included in the list because the two "phases" are not simply mechanically separable. Otherwise these processes are fundamentally similar in operation to the

separation processes listed.)

Fractional crystallization

For practical purposes the adsorbed phase and the solid adsorbent are one and the same as far as mechanical handling is concerned. In every case at least one of the phases is fluid. In operation the two phases are passed countercurrently to each other. Means are provided to bring the phases into equilibrium with each other while simultaneously the countercurrent flow continuously separates phases approaching equilibrium and places them in nonequilibrium situations. Finally, the concentration of one component relative to

A pilot plant model of a continuous fractional crystallizer which is capable of producing 300 lb./hr. of pure hydrocarbon product.



another component of the mixture to be separated is less in one equilibrated phase than in the other.

The means used to perform these fundamentally similar operations and to calculate the equipment size and design differ enough to give rise to separate and distinct treatments in textbooks and handbooks. In fractional distillation the two phases being handled are similar in composition. Because of this phase similarity certain simplified methods have been devised for calculating fractionators. Gas absorbers are usually calculated by another method. Extractive and azeotropic distillation do not lend themselves to the simplified calculating procedures used for the other vapor-liquid separation processes. The same applies to solvent extraction, adsorption and fractional crystallization. Not only do simplified calculation methods developed for the other processes prove inadequate for these processes but in fractional crystallization and adsorption the difficulty of handling solids in a flow system and, in the case of crystallization, the slowness of approach to equilibrium and the effects of occlusion introduce problems unusual to other methods of separation. Within the last few years largescale industrial use of continuously moving beds of solid adsorbent has been successful (25) so that the analogy between continuous fractional adsorptiondesorption and fractional distillation is

Why have these separation processes been treated as distinct operations? The distinctions arise in part from the development stages of the several separation methods. Only in comparatively recent times have enough fundamental data been accumulated to explain the method of operation of these processes and the fund of data is still inadequate. In early development, the practical knowledge was obtained by bitter experience and results were expressed empirically and reflected the individual peculiarities of the processes rather than the inherent similarities. Today, with a greater fund of information there is no excuse to continue artificial distinctions among separation processes. Rather, their similarity should be stressed so that useful information learned on one process can be used to assist in designing and operating another process. If this is done, not only can general and specific knowledge be applied more effectively to all operations but the real differences between the processes can be given special attention for their better understanding.

Characteristics Distinguishing Separation Processes

Similarities among separation processes have already been mentioned. Difof the key or main constituents. Heat

ferences arise from several characteristics. Restricting this discussion to the more difficult separations where concentration change and temperature change per equilibrium step are small or moderate, these are:

1. Source of contacting energy.

Ease of phase separation.
 Rate of approach toward equilibrium.

Fluidity of the phases.
 Relative size of the phases.

6. Equipment size.

The source of contacting energy in bubble-tray towers is almost entirely the expansion of the vapor phase. When the pressure drop per bubble tray is 0.1 lb./sq.in., the energy used per tray is about 1500 ft. lb./lb. mole of vapor passed through the tray at 60 lb./sq.in. abs. and about 230 ft. lb./lb. mole at 400 lb./sq.in. abs. Not all this energy is used in actual contacting, part being consumed in the passage through the interior of the bubble-cap assembly, Also, at high pressures, the lower density of the liquid phase (in ordinary distillations) may make use of as high a pressure drop as 0.1 lb./sq.in./tray unsafe. Hence the available mixing energy in high-pressure columns may be much less per unit material contacted, in comparison with a moderate pressure operation, than the 1 to 6.6 ratio found in the example. High-pressure towers often are disappointing in their operating performance.

Low-pressure towers, for instance those operating in the region of 100 mm. Hg abs., cannot afford the high-pressure drop used in above example. A pressure drop per tray of about 2 mm. has been found to give good results in ordinary bubble-tray vacuum towers. This amounts to an expenditure of about 18,000 ft. lb. of energy per pound mole of vapor. Even after subtracting a generous amount for the energy wasted in the bubble-cap passages there is a much larger amount of energy available for contacting in vacuum towers than in moderate pressure towers.

Bubble trays are not satisfactory for difficult separations at higher vacuums. The 2-mm. pressure drop per tray found desirable in vacuum towers is not so much demanded by the energy requirement of the contacting step as by the necessity for maintaining a reasonably uniform degree of contacting all over the bubble tray. Misalignment, liquid gradient and other factors tending to give poor distribution must be compensated by what amounts to an excessive pressure drop compared with what is required for adequate contacting. A distillation requiring a maximum of 20-mm. abs. pressure and at least twenty bubble trays obviously cannot operate with 2-mm. pressure drop per tray. Some method of using the energy of expanding vapor efficiently is needed for such low pressure operations. Only about 0.03-mm. pressure drop per tray is required to give energy equivalent to that used for moderate pressure distillations. This would amount to only 0.6 mm. in twenty trays, a pressure drop that would be welcomed by an operator of a vacuum tower.

Another commonly used source of energy in separation towers is liquid head. For a material having a mole wt. of 58 and 0.55 sp. gr. (saturated butane at 60 lb./sq.in. abs.), the net difference in the densities of the liquid and vapor phase is 33.8 lb./cu.ft. If the contacting steps are placed 2 ft. apart, vertically, the maximum energy per tray from liquid head will be 114 ft. lb./lb. mole or about one-thirteenth that available from expanding vapor. Shower decks and spray towers depend largely on this source of driving energy. One would not expect them to match bubble trays in their performance. Packed towers derive part of their contacting energy from this source and part from vapor expansion. Solvent extraction towers depend entirely on liquid head energy unless jet agitation (pressuredrop energy) or outside mechanical energy (stirrers) is used. The amount of outside mechanical energy that can be used per contacting step is unlimited by the properties of the system but this method requires a considerable investment in stirrers and driving members and is subject to serious maintenance troubles.

Ease of phase separation, the second item among causes of separation process differences, is often forgotten. Liquid with foaming tendencies or emulsion-forming tendencies must not be agitated too vigorously with the other phase, or an inordinately large separating volume will be required per contacting step. The advantage of intimate contacting will be far outweighed by the disadvantage of the difficult phase separation. In such cases there is an optimum degree of contacting, much less than usual, which gives the lowest over-all investment.

The rate of approach toward equilibrium is a factor having a great deal to do with the type of equipment used, its design and its operation. This factor is taken into account in the tray efficiency factor in bubble-tray columns or the HETP (height equivalent to a theoretical plate) in a packed column for separations where approach to equilibrium is fairly rapid. The other extreme is found in absorption towers where chemical reaction takes place (digressing for the moment from the scope covered by purely physical operatigns). In these operations, one equilibrium step may be adequate but the tower height or volume may be equal to that of a distillation unit containing many equilibrium steps. The method of calculation for such cases obviously must put its emphasis on transfer or reaction rates, not on equilibrium steps. Examples can be found in industrial operations for cases covering the range from practically instantaneous attainment of near equilibrium to processes requiring hours to approach equilibrium. Superficially the contacting towers for these extreme cases may look similar but the controlling factors will be quite different.

The fluidity of the phases has much to do with determining the type of contacting device. Adequate contacting is easy when both phases have low viscosity. Contacting and subsequent separation are quite a problem when one or both phases become viscous. Special means of handling, which may be quite different from those used when both phases are fluid, must be used when one phase is solid. Sometimes the solid phase, such as an adsorbent, is not moved but remains in a fixed position in a series of beds or vessels. The other phase is made to contact the solid phase countercurrently by introducing and withdrawing it at various consecutive points in the series of beds by means of a suitable arrangement of pipes and

The relative size of the phases may have an important effect on the type of contacting device. A suitable means for contacting two phases when the heavy phase is many times as large as the light phase is not likely to be satisfactory for contacting where the relative quantities of the phases are reversed.

Equipment size itself has an important effect on the type of contacting device used. Laboratory devices do not look much like industrial units. Fractionating towers less than 30-in. diam. are usually packed towers while larger units are generally bubble-tray towers. There are three reasons for this change in style with size:

Interrelationships of space - time - mass cannot be kept constant or similar through large changes in size of equipment. design for a small unit may be a failure in large unit. Construction and maintenance limitations may make impractical building units of a certain style larger or smaller than a given size. Bubble-tray columns less than 30-in. diam. are not often used industrially because of the construction and maintenance difficulties. The third reason is the changing ratio of labor cost to investment as size changes. It takes about as much labor to operate a small unit as a large unit. In a small unit the investment cost may be insignificant compared with the labor cost. Expensive construction and design practices may be tolerated. The reverse is true for a large unit.

Fractional-Distillation Generalizations

An understanding of a few generalities concerning separations can be of great assistance to a plant operator. The following remarks specifically refer to fractional distillation but they generally apply to any separation requiring a considerable number of equilibrium steps.

A convenient method for measuring the difficulty of a separation is by the α factor. This factor is defined as

$$a = \frac{y_i x_j}{x_i y_j}$$

where x_i , y_i and x_j , y_j are respectively the liquid- and vapor-equilibrium concentrations of components i and j between which a separation is being made. Since the equilibrium-vaporization ratio is defined as

$$K_i = \frac{y_i}{x_i}$$

and since at moderate and low pressure in mixtures of closely related compounds which have nearly the same boiling points

$$K_i = \frac{P_i}{\pi}$$

where P is the vapor pressure of i and π is the total pressure on the system, it follows that

$$\alpha = \frac{P_i \pi}{\pi P_j} = \frac{P_4}{P_j}$$

The ratio of the vapor pressures of related compounds and, in general, of most compounds changes only a little for a moderate change in temperature, usually decreasing (if greater than unity) with increase in temperature. Unless compounds are similar they may not form "ideal" solutions, one in the other. One way of defining an ideal solution is to classify all solutions which obey the formula

$$\alpha = \frac{P_i}{P_i}$$

as ideal after making corrections for pressure effects. In the type of nonideality usually encountered, the effect on a is to make it larger than the value in the above definition when the j component is preponderant and to make it smaller when the i component is present in the higher concentration. The relative change of vapor pressures with temperature is such that when i is the more volatile component a increases with increase in and decreases with increase in j. Hence, for very small amounts of nonideality the tendency is to compensate for the usual change in the a value so that a may be more constant in a fractionator operating on an actual mixture than would be the case for a perfectly ideal mixture.

Even in the case of rather nonideal systems such as olefins in paraffins and diolefins in olefins, use of an a, defined by vapor pressures, to measure the ease of separation may not be seriously in error. The nonideality usually encountered is such that the effect on the two components of a binary mixture is the same when the mixture contains about equal quantities of the two substances. Since the volatility of each component has been increased in the same proportion the true a is the same as the estimated a. If the nonideality is not so great as to shift the pinch from near the feed entry to some other part of the column, the reflux requirement remains the same for ideal and nonideal mixtures of compounds with the key components having the same vapor-pressure ratios where feed compositions are about 50 per cent (binary mixtures). More equilibrium steps will be required above the feed entry for the nonideal case but fewer below the feed entry. The total number of steps will be somewhat larger, increasing rapidly as the nonideality increases toward the point where the pinch is no longer at the feed entry.

Briefly, a's based on vapor pressures can be used for preliminary studies and estimations for a large portion of the problems encountered in the more difficult fractional-distillation separations. If no evidence is available to judge the possible extent of nonideality, some phase-equilibrium determinations should

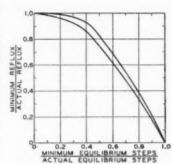


Fig. 2. Equilibrium steps-reflux relationship.

be made before making important decisions,

The following generalizations are necessarily based on binary mixtures in order to keep the formulas and curves usably simple. Multicomponent mixtures will qualitatively follow the same rules where the key components are represented by the binary pair in the generalization and the other components in the mixtures remain essentially constant in quantity and quality.

When a separation is expressed as fraction of composent i recovered in the overhead product and fraction of composent j recovered in the bottom product, a useful generalization may be made. For a given R_i and R_j , the minimum reflux, based on the feed, and the minimum equilibrium step requirement remain constant regardless of changes in the ratio of i to j in the feed. Note that the separations are expressed as fractions recovery, R_i and R_j , not as purifactions recovery, R_i and R_j , not as purifactions recovery.

ties of products. For moderate changes in the ratio of i to j in the feed either method of expressing the separation will be adequate. However, the fraction-recovery method is not limited to any range in feed composition change. Note also that the reflux (liquid down-flow per unit time in the column above the feed entry) applies to a constant feed rate, or the ratio of the internal reflux to the feed remains constant. The feed is assumed to enter as a liquid at about the temperature within the column at the point of feed entry. Although for all prac-tical purposes the total number of equilibrium steps required does not change, the position of the feed entry does, being higher for a feed rich in the less volatile component and lower for a feed rich in the more volatile component. Note the movement of the feed entry contrary to what would seem reasonable.

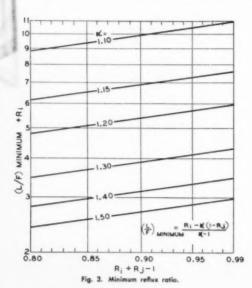
Minimum reflux ratio and minimum number of equilibrium steps are important and valuable factors to know about any separation of interest. Minimum reflux ratio (reflux rate divided by feed rate) is the least reflux that can be used and still obtain a given separation with an unlimited number of equilibrium steps. This ratio is not simply determined for a multicomponent mixture but for a normal binary mixture it may be found from the equation

$$\frac{L}{F} = \frac{R_i - \alpha(1 - R_f)}{\alpha - 1} \tag{1}$$

where the L applies above the feed entry and entrance of the feed does not change the vapor rate in the column at that point. Minimum number of equilibrium steps is the least number of equilibrium steps required to make a separation with an unlimited reflux $L/F=\infty$. For a binary mixture with a constant α , a modification of Fenske's equation gives

$$\alpha^{x} = \frac{R_{4}R_{3}}{(1 - R_{3})(1 - R_{4})} \tag{2}$$

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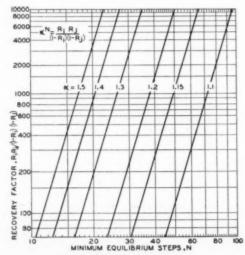


Fig. 4. Minimum equilibrium steps.

$$N_{(848.5)} \simeq \frac{\log \left[\frac{R_4 R_j}{(1 - R_j)(1 - R_4)}\right]}{\log a}$$
(3)

where Nontan equals the minimum number of equilibrium steps required for the sepa-

The most important information carried in the minimum values is that for any given separation more reflux than the minimum and more equilibrium steps than the minimum must be provided before the separation can be made. These factors not only give the limiting minimum values but they also give practical operating values. Figure 2 is a graph of the minimum reflux ratio divided by the actual reflux ratio plotted against the minimum number of equilibrium steps divided by the actual number of equi-librium steps. The curves on Figure 2 were calculated for a's ranging from 1.1 to 1.5 (difficult separations) assuming a's and molal overflows constant throughout the fractionator and expressing reflux ratio in a tractionator and expressing reflux ratio in terms of the feed and separation in terms of fractions recovered. When the feed composition is near equal molal concentrations of the two components the outside (upper) edge of the band applies. When the feed contains considerably more of one component than the other, either the more volatile or less volatile, the inner (lower) edge of the band is approached. The inner edge represents feed compositions of four parts one component to one part the other component. Charts of this type have been published before. One by Brown and associates (3) does not agree with Figure 2 as well as would be expected The reason for this disagreement probably lies in the methods used in deriving the charts.

Figures 3 and 4 are constructed from Equations (1) and (2) and are companion charts for Figure 2. A corollary of these charts is that many equilibrium steps should be used with a large reflux ratio or, conversely, a large reflux ratio with few trays is an inefficient manner of operation. A con-venient rule to remember is that 60 per cent more than the minimum reflux with 60 per cent more than the minimum number of equilibrium steps gives a fractionator capable of making a given separation.

Notation

 $A = absorption factor = \frac{L}{KV}$

F = feed rate, moles per unit

 $H_4 - H_4^{\circ} = \text{differential heat of solution}$ K = phase equilibrium ratio

L = liquid rate = heavier phase rate of flow, moles per unit time

N = equilibrium step number

P = vapor pressure

R = fraction recovery (of a component in a product stream)

R = gas constant, used in Equation (9) only

$$S = \text{stripping factor} = \frac{KV}{I}$$

 $S_F =$ solvent entering with feed, moles per unit time

T = absolute temperature

V = vapor rate = lighter phaserate of flow, moles per unit time

(A) = absorption factor, solventfree basis = $\frac{(2)}{(K)(V)}$

(K) = phase - equilibrium ratio, solvent-free basis = $\frac{(y)}{(x)}$

(L) = liquid rate, solvent-free basis (S) = stripping factor, solventfree basis = $\frac{(K)(V)}{(V)}$

(L) (V) = vapor rate, solvent-free basis

In = natural logarithm

x = concentration in heavier phase, mole fraction

y = concentration in lighter phase, mole fraction (x) = concentration in heavier

phase, solvent-free basis (y) = concentration in lighter

phase, solvent-free basis $\pi = \text{total pressure on system}$

a = relative volatility

 $\gamma =$ activity coefficient

 $\phi = \text{differential operator}$

 $\Delta_x = \text{change in } x \text{ concentration}$ per equilibrium step

 $\Delta_i = \text{moles } i \text{ passing a given}$ point per unit time in lighter countercurrent stream minus moles i passing same per unit time in heavier stream

 $\Delta_{\Sigma^{i,j,k}} = \text{total moles in lighter stream}$ minus total moles in heavier countercurrenting stream passing a given point per unit time

SUBSCRIPTS:

H = n-heptane

P = pressure

T = toluene

x = concentration

i = component i

i = component j

k = component k

n = equilibrium step number

s = solvent

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CHEMICAL MARKET RESEARCH-WHY?

A Statement of Purpose

THE evolution of the chemical industry has developed a variety of specialists to cope with the problems characteristic of its intricacy. Like interpreters who think in two languages, hybrids developed by the industry include the chemical engineer, the chemical patent attorney, the technical salesman, and—the immediate concern of this series of papers—the chemical market researcher. All of the specialists must combine technical insight with commercial understanding.

The basic purpose of industrial market research is to develop and analyze information on supply, demand, and prices to answer three major questions: How much of this product can be sold? How much of this market can be secured? What competition must be faced?

The final objective is forecasts realistic enough to serve the planning of sales managers on regular products, of research directors on new products, and of management on the over-all problems of growth.

In terms of career, steppingstone, or simply better understanding of company teamwork, market research is of high interest to the chemical engineer. The papers of this symposium, published here and in forthcoming issues, outline problems and procedures in chemical market research including the economic background of the industry, the functions and organization of a market research staff, examples of successful practices, and the sources, both published and in the field, open to chemical market researchers. Throughout these papers the chemical engineer will note with interest the interaction of the many technical and commercial forces that meet in the market place.

-R. M. Laurence



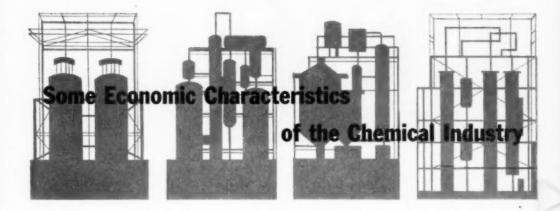
Richard Marston Lawrence, vice-president of the Chemical Market Research Association, has been with Monsanto Chemical Company in the General Development Department since 1947. Previously he did chemical market research for Atlas Powder Company for ten years and was a chemical expert for the U. S. Tariff Commission from 1931 to 1937. Mr. Lawrence has a B.S. in chemistry from the University of California and an M.S. in chemical engineering from the University of Illinois. He is a member of the American Chemical Society and the American Marketing Association and the author of several books in his field. Besides being chairman of the symposium on chemical market research for the A.I.Ch.E. Atlanta meeting, Mr. Lawrence is co-author of one of the papers in the symposium, to be published in a later issue.



An engineering graduate of Tulane University, M. W. Leland joined Shell Chemical Corporation in 1928 and spent ten years in refining technology, advancing to be chief technologist at the company's Houston refinery from 1936 to 1939. He was then transferred to the manufacturing department of the head office, where his work on processes and economics of aviation fuel involved serving on government committees and helping to devise new processes for aviation-fuel components, one of which was cumene. From 1943 to 1945 he served as a major on the staff of the Under Secretary of War, specializing in aviation-fuel matters. With Shell since 1945 as manager of economic research, he has been responsible for formulating chemical-industry forecasts and conducting a continuing study of the competitive economics of a large number of chemical products.



Parker Frisselle is manager of the Market Research Department of Dow Chemical Company, Midland, Michigan, a position that he assumed in 1950 after seven years with Dow's Western Division and home office in the sales and the technical service and development groups. Previously he had worked as a chemist and assistant production manager for California Products Company. Born in Fresno, Calif., Mr. Frisselle graduated from Stanford University with a degree in chemistry in 1935 and in 1937 received an M. B. A. from Harvard University.



M. W. Leland

O provide a background of economic characteristics of the chemical industry is not an easy task, because the chemical industry is not a single homogeneous entity, but rather a collection of many businesses or industries. To describe the characteristics of a particular phase of the industry would be easier than to characterize the total. However, the interrelationship of the many pieces of the industry is one of the most important problems facing anyone doing chemical market research and hence is logically a part of any background discussion. There is no clear-cut agreement as to where the chemical industry starts and where it ends. Individuals working in one phase naturally emphasize their particular business and tend to minimize other aspects. Even the government agencies use different definitions in their inclusions, for example, in terms of familiar products: Is benzene a product of the chemical industry or the coal-tar industry or the steel industry or the petroleum industry? Is rayon a separate industry or is it part of the chemical industry?

At the risk of incompleteness or oversimplification, an attempt has been made at a description (see Figure 1) of the chemical industry, an attempt at a functional definition from an engineering viewpoint. The concept is that the industry contains three phases: recovery of raw materials, production of industrial chemicals, and production of chemical products.

From the raw-material list it is noted that the industry is basic, that it starts from holes in the ground. It is complex, however, because it starts with a great number of holes in the ground. raw materials have been divided into five groups. The chart (Figure 1) is not complete, as it shows only a few important examples of each of the five types and omits two raw materials of lesser economic importance, air and water. Of the five groups shown, only in the case of one group, the nonmetallic minerals, are mining operations generally considered part of the chemical industry. In this case the chemical industry is the principal consumer of these raw materials. The other four types of raw materials, of which the bulk of the product is used for other purposes, are generally considered as pertaining to other industries. The chemical industry does use small parts of these materials, however, and so from the chemical-industry viewpoint they are extremely important.

The next step is the production of industrial organic and inorganic chemicals. The complexity continues here, too, as this phase represents a great number of processes and thousands of individual chemicals. Many of these chemicals are made from one another; for example, ethyl alcohol is used to make acetaldehyde, which is used to make acetic acid. which is used to make acetic anhydride.

The third phase is chemical products, and it is here that the bulk of the industrial chemicals is consumed. The diagram does not provide for the significant

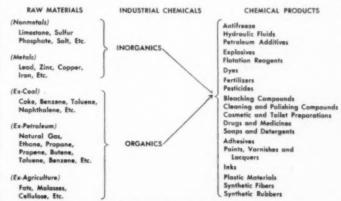
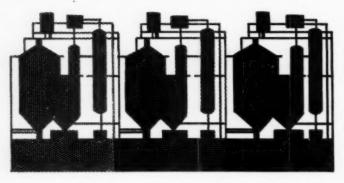


Fig. 1. Diagram of the chemical industry.



amounts of industrial chemicals which flow directly to such process industries as glass, paper, and petroleum; however, there are thousands of individual products grouped on a functional basis. Related directly or indirectly to most of our modern needs, they run the gamut from antifreeze for our automobile, to explosives for mining, to fertilizer for our food, to drugs for our health, to paint for the appearance and protection of our home and its contents, to fibers for our clothing.

Perhaps this brief indication of the components of the industry is illustrative of one of its important characteristics, its functional complexity. There are other industries, such as petroleum, which make a multitude of products out of one raw material. Some industries, such as the automobile, make a single product out of a multitude of raw materials. But the chemical industry tops them all for complexity, starting with a multitude of raw materials, carrying through thousands of industrial chemicals, and arriving at the multitude of chemical products.

A second broad characteristic is that it is dynamic. There are two general aspects to this concept. One can be described by the much-used term 'growth." The other concerns changes and substitutions, sometimes involving rapid obsolescence. Much has been written about the growth of the industry, and the statistical record is most impressive. The industry for the most part is growing faster than the general economy, primarily because it is increasing its contribution to many phases of the industrial picture. A few examples are: the use of fertilizers, which is growing faster than the production of food; the increasing use of rayon and other synthetic fibers; the penetration of synthetic rubber to over 50% of total rubber consumption; the advent of synthetic detergents, which claim one third of the field of cleansing materials; and plastic materials, used in place of wood, leather. metals, and ceramics. On the other

hand, as examples of the dynamics of change, one can recognize the decreasing importance of the manufacture of soap from natural fats and of alcohol by the fermentation of molasses.

A third characteristic of the industry is that, in the nomenclature of the economist, it is a service industry. This is simply a way of saying that it serves other industries rather than having its principal products go directly to the end consumer. But in more ways than in the academic concept the chemical industry is truly a service industry. It not only serves practically every phase of the industrial community, but does an outstanding job in providing new and better products to the other industries. This characteristic has created a large demand for technical manpower. not only for research, manufacturing, and process development, but also for technical service and marketing. Technical service in the chemical industry embraces the type of customer service performed in many industries and in addition a more elaborate service designed to help find the proper technological place for new products and to help the user of these products to utilize them most efficiently.

Competition is a fourth broad characteristic. There may be places in the economy where the competition is more obvious or more newsworthy, but there is no place where it is more diverse. At least four types of competition are present in the industry: competition between products finds isopropanol and ethanol or sorbitol and glycerine competing for similar markets; competition between processes is exemplified by at least four processes in use for making phenol from benzene, and some ten processes for making acetic acid, starting with three raw materials; competition between raw materials gives rise to ethanol produced by synthesis from petroleum ethylene and ethanol produced from fermentation of molasses, or phthalic anhydride produced from coaltar naphthalene and from petroleum ortho xylene, or synthetic detergents from petroleum fractions competing with soap produced from natural fats; and of course there is the more usual type of competition, that between companies.

These and many other characteristics of the industry must be considered by people doing chemical market research. It is not possible to cover all of them, but it would be amiss not to discuss money. The requirements of the chemical industry for capital are large: for expansion, for research, for technical service. And in a complex industry which is dynamic and competitive, expenditure of large amounts of money means large risks. The most important pertain to investment in new plants, either to produce new products or to expand production of old ones.

Risk is another complex characteristic. There are several types of risk involved in any new project. The manufacturing risk, particularly when a process is new, is whether it will work. whether it will produce the designed amount of material, whether it can be built and can produce at the estimated cost. The marketing risk entails selling the product, and selling it in the quantities estimated and at the price anticipated. Also, there is always the overriding risk that the general economy may be operating at a lower level when the plant is finished than at the time when it was authorized. But the greatest risk. in the chemical industry, is in the money appropriated for research. This risk, however, carries with it the greatest potential gain and is obviously the mainspring of new developments and new products. To assess the justification and risk for sizable expenditure of funds, is the function of market research.

Chemical market research is usually a part of a general development program, and the most important results of a development program involve decisions on new plants, new construction. In such activity market research cannot avoid dealing in futures. One means of forecasting is the use of extrapolation or mathematical projections, which are not difficult to make but are often difficult to assess. In the complicated system of competition in this industry. however, such a forecast may not be good enough for a project involving large risks. There is no substitute for a thorough understanding both of the flow of materials in this complex industry and of the competitive and other economic forces. The proper analysis of such situations requires a broad background in chemistry, engineering, and economics. It is not surprising, therefore, that market research increasingly offers opportunity to chemical engineers.

Functions

of Chemical Market

Research



Parker Frisselle



BROADLY speaking, market research has one basic objective, to answer the all-important questions who? what? where? when? Who will buy what chemical in what quantities of what quality at what price in what containers against what product competition and against what company competition? Where will they buy? Is the market on the west coast-in the south? Is it an export market? How distant is it? Finally, when will they buy and for how long? Generally speaking, manufacturers are not interested in temporary markets. They must know when the market will open and whether it will maintain itself or disappear after a particular need has been met. Market researchers feel that the answers to these questions are important to research, production, purchasing, sales, and management.

How are these questions answered? We at Dow answer them by five general methods: product surveys, industry surveys, area surveys, sales forecasting. and trade-sales analysis.

As an example of a product survey, our market research department was asked a few years ago by our sales department to determine the national market for triethanolamine. Our company has made triethanolamine for a number of years; in 1949 we produced and sold a small percentage of national production. Specifically, we were asked, is the national market large enough to make expansion by Dow profitable? One hundred and twenty-six personal calls later we had an answer.

There was approximately 17,000,000

lb. of triethanolamine sold annually in the country, we learned from an investigation made in the latter part of 1950. Obviously, there was a sizable national market that offered considerable opportunity for the expansion of our production. But there were other factors to be considered. We had also determined competitive productive capacity to be about 16,000,000 lb. Adding in our sales, we came out with an answer which made it appear that there was no shortage of triethanolamine in the market. Therefore, we should not have been interested in increasing our production.

We knew, however, from the survey that there was a greater shortage than these figures indicated; and so we had to adjust the figures by yet other considerations. We learned that one manufacturer was diverting ethylene from ethanolamine production to ethylene glycol and other ethylene uses. We knew that another had just come into production, and we knew that still another would probably be coming into production in the latter part of 1951. After considering all facets of the problem, we finally arrived at an estimate that there was probably a 5 to 6 million lb. market open if we moved quickly

We had answered the original question, is the national market large enough to make expansion profitable? and we had pointed out the extent to which the market was short. We had thus narrowed the field of executive decision by developing as many facts as possible about the market and putting them in the hands of people who have to make the decision.



A second example of a market research function is an industry survey. An industry survey, as we use the term, is generally made on an old, established product, the investigation is usually more intensive than is a product survey, and it is a continuing study, in that we plan to keep up with developments through the years. Caustic soda is a good example.

We were asked by our management about two years ago to study the caustic soda picture and to develop a sales tool that our salesmen could use to get more business for this product. At that time the chemical industry had a surplus of caustic soda and a very serious problem

in disposing of it.



The goal-finding the market.

In this survey, we started with historical information, plotting the growth of both electrolytic and lime soda caustic. total national caustic consumption, and other industry data. We then brought the study down to a more personal basis and showed why the problem was acute for Dow particularly. We plotted Dow chlorine production from 1934 to 1949 to show its tenfold growth and made a comparison of Dow's position with the total industry. We showed that in the period 1939-1949 national consumption of caustic soda had approximately doubled. Dow's production of caustic soda during the same period had gone up sevenfold, and our sales of caustic soda had risen between fiveand five-and-a-half-fold,

We then went from that into a study of our competitors. We identified the plants by location, determined their capacities, worked out a picture on the competitive situation, and then passed from that on into the caustic-consuming industries. We made a study of four of the major caustic-consuming industries, listing in our report by identity and by geographical location 337 oil refiners with a 200,000-ton/yr, capacity to consume caustic, 166 paper mills with

the same capacity, 13 rayon and cellophane companies who could consume 500,000 tons of caustic, and 49 rubber reclaimers who could consume 26,000 tons. This total of 926,000 tons was almost half of the national production of caustic at that time.

In making these figures available to our men, we broke things down to show them in detail where this potential business in caustic soda could be found. We listed the capacity of the oil refineries in barrels per day to refine oil-that gave the salesman an idea of the size of the unit with which he was dealing. Then we calculated the potential caustic consumption of the refinery at 100% operation. Finally, we listed what the salesman told us he expected to sell to each refiner. Putting the report in this form has two advantages; it identifies the individual customer, shows what we should be doing with each, and, more important from the standpoint of selling, gives each salesman a work sheet with which completely to cover the valuable consumers within an in-

All the industries mentioned, rayon, paper, petroleum and rubber, were broken down in this way, to individual plants, to act as a sales guide. In addition, we have now almost completed listing all vegetable-oil refiners, all sizable soap manufacturers, all lye manufacturers, and all textile finishers. We hope to add to this list all chemical manufacturers and miscellaneous users, thus covering total national caustic consumption.

Passing from an industry survey, let us discuss an area survey. We recently opened a new sales office in Atlanta to serve the area covered by North and South Carolina, Alabama, Georgia and Florida, calling this our Atlanta territory. The sales department was very interested in knowing how the area measured up to the rest of the United States—what sort of territory were we going into? was it a particularly good

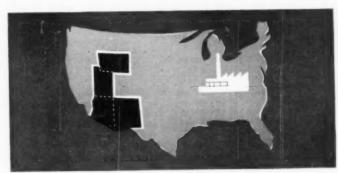
chemical consumer, an average one, or a poor one?

The population of these five states is 10% of the United States total. In making a comparison, therefore, with other areas where we sell our chemicals, we can estimate that if they have 10% of the population, they should have 10% of the industry, 10% of the farming, 10% of national income-and they should buy 10% of Dow's products. This vardstick is debatable, but we find it a good measure of an area. How does the area measure up? Eight and ninetenths per cent of the chemical-consuming industry of the country, measured by the value that is added by manufacture, is located in the Atlanta territory. However, this area is very heavy on textiles, and textiles in general are not particularly good consumers of our products. When we remove the textile segment of the chemicalconsuming industry, the remainder is down to 3.7% of the national total. On this basis, the area is not so industrialized as the average state in the United States, and, furthermore, we have to keep in mind that the average in the United States includes such states as New Mexico, Arizona, Utah, Wyoming and similar places where there is virtually no industry. So we find the Atlanta territory somewhat behind the average of the country and certainly behind good chemical-consuming areas like Chicago, the Central Atlantic seaboard, and industrial New England. The rate of growth in these five southern states, however, was 20% above the national average during the period 1939-1947.

We then took a look at total income. With 10% of the total population in the United States, the Atlanta territory has only 6.6% of the income. This means that as consumers for products of our manufacture or things which are made from our products, the people in this area are not up to the United States average.



Four major caustic-consuming industries



Area survey reveals some barren spots.

In regard to the farming situation, the Atlanta territory has 7.4% of the farm area and 7.9% of the farm income. The income per acre is quite well balanced. However, these five states with only 7% of the nation's farm. This means that each farm is less than half as big as the national average and the perfarm income is less than half as large as it is for the average of the United States. So the general picture is that this is a poor area in which to sell agricultural chemicals.

From here we pass to a study of the individual industries in the Atlanta territory. What could we expect in the way of different types of industry? How big would they be compared to the rest of the United States or compared to the average of each state? As mentioned previously, the biggest industry in this five-state area is textiles. 35% of the nation's capacity lying in the five states. The next largest industry is paper, followed by food products, chemicals, etc. Conspicuous by their absence are significant petroleum, rubber, and leather industries.

We added to this statistical analysis, a study of the location and operations of our competitors. In the territory

there were 40 companies with 61 sales offices and 63 factories. We added to that a list of 2856 potential customers of whom we had no previous record, as an aid to our salesmen in beginning their development of the area.

In making this economic and industrial study, of which this is only a brief outline of the actual work done, we think that we gave our sales department and management an idea of the economic climate into which we were moving. We showed them that on the basis of population almost every activity and measure of economic strength in this area is below normal for the United States and that, therefore, the area does not represent as good a market as we would have hoped to find.

The fourth market research function is sales forecasting. Our market research department prepares a sales forecast every month for production. We actually do no forecasting ourselves but act as a consolidating point or clearing house for anticipated monthly or quarterly figures given to us by various product managers within the sales organization. We put them in usable form and then pass them back to production for scheduling use. The same forecast is given to the sales department every 3

months, showing what sales are estimated to be in both pounds and dollars, and that same report is also used by management. In addition to this short-range or yearly sales forecasting, we annually prepare a 5-year sales forecast in much the same manner. This is used for long-range planning within our company. It enables management to plan the financial, physical-plant, manpower, and raw-material requirements for our growing company.

The last of our major functions is what we call our trade-analysis system. This is a method of keeping track of our customers on IBM cards. We record our sales to them, and, equally important, we try to keep track of what our competitors sell them, as well as how they use our products. By adding together our sales and our competitors' sales, we, of course, can arrive at the total national market. While the government publishes figures on about 10% of our chemicals, the national sales of the other 90% must be developed in the preceding manner. If we are going to do an intelligent job of planning production, selling, and plant growth, we must know exactly where we stand in any given market for a given chemical, and for this information we rely on the trade-analysis system, which is based on our salesmen's reports of call, sent in on each customer. Once the information is fed into IBM cards, we are able to break it down by areas, by branches, by states, by salesmen, by industry, by company, by use, by competitor, and by almost any combination of these classifications. Trade-sales analysis is an extremely useful tool from the standpoint of both market development and management control.

There are many other jobs that market research can and does perform; however, in my opinion these five are the most significant.

Market research makes two important contributions. First, it lowers the cost of products by the study of markets: it ensures that adequate production is available when the market requires the product; and on the other hand it makes certain that too much capacity for the production of a given product is not built by ill-advised optimism about a market. Market research lowers the cost of products also by proper plant location between raw material and market and by better distribution. Second, in lowering the cost of products, market research prevents economic waste both within an individual company and within the nation. This prevention of economic waste is of growing significance in a country that has squandered its resources like a drunken sailor and is now called upon to contribute billions to the support of most of the free world.



Foresight and the market.

PLASTICS EQUIPMENT REFERENCE SHEET

RAYMOND B. SEYMOUR and ROBERT H. STEINER

The Atlas Mineral Products Co., Mertztown, Pa.

SARAN: This unfilled, slightly flexible thermoplastic material is available in the form of sheets up to 1/2 in. in thickness, rods and pipe up to 4 in. I.D. Molded fittings are available for all sizes of pipe.

APPLICATION AND REMARKS: Sheet may be formed, drawn or welded to form chemical resistant structures such as ducts, hoods, plenum chambers, stacks,

splash covers and tanks. Welding is more difficult than with rigid polyvinyl chloride

or polyethy-

lene. Special shapes can be injection-molded. The major use of Saran in the chemical process industry is in the form of extruded tubing and as lined pipe.

CHEMICAL COMPOSITION: Copolymers of 85-95% vinylidene chloride with 5-15% vinyl chloride or acrylonitrile plus small amounts of plasticizers, pigments and stabilizers.

MACHINABILITY: May be heat-formed by the use of dies or blowing techniques, welded by hot gas process using Saran welding rod, heat-sealed, cemented, ground, turned, sanded, stamped, drilled and milled. Since it is thermo-plastic with a sharp melting point, a coolant is recommended in many machining operations. Sheets should be welded at 300-400° F.

TYPICAL MECHANICAL AND PHYSICAL PROPERTIES:

Tensile Strength, lb./sq.in. . . Tensile Strength, lb./sq.in.
Elongation, f;
Impact Notch, Irod lb./in.
Hardness, Rockwell M
Flexural Strength, lb. sq.in.
Modulus of Elasticity (x 10° lb./sq.in.)
Specific Gravity
Heat Distortion (*F.)
Specific Heat (B.t.u./(lb.) (*F.) 70-150° F.)
Thermal Expansion (in. in. "F. x 10° b/ 770-120° F.)
Thermal Conductivity, B.t.u. (sec.) (sq.ft.) (*F./in. x 10° b/ 70-120° F.)
Dielectric Constant, 10° cycles Dielectric Co Flammability self extinguishing TEMPERATURE LIMITATIONS: Not recommended for service at temperatures above 160° F.

CORROSION RESISTANCE

1	C	H		C	H		C	94
ACIDS Acetic, 10%	E	F	ACID SALTS Alum or Aluminum sulfate Ammonium chloride, nitrate,	E	E	Ethylene dichloride	N E	NEEE
Acetic, glacial Benzene sulfonic Benzoic	E	E	sulfate Copper chloride, nitrate,		E	Phenol. 5% Refinery crudes Trichloroethylene	E	EEZ
Boric Butyric	E	EEZZ	Ferric chloride, nitrate,		E	PAPER MILL APPLICATIONS		
Chromic, 10%	E		Nickel chloride, nitrate,	E	E	Kraft liquor Black liquor Green liquor	F	7.7.7
Fatty Acids (Ca-Cia)	EEE	EFEREPEEE	Stannic chloride Zinc chloride, nitrate, sulfate ALKALINE SALTS	E	E	White liquor Sulfite liquor Chlorite bleach Alum	E	ZEZE
Formic	E	E	Barium aulfide	E	E	PHOTOGRAPHIC INDUSTRY	L	-
Hydrocyanic Hypochlorous Lactic	E	EEE	Sodium carbonate Sodium carbonate Sodium sulfide Trisodium phosphate	E	EEE	Developers General use Silver nitrate	E	EEE
Maleic Nitric, 5% Nitric, 20%	E	EEG	NEUTRAL SALTS			FERTILIZER INDUSTRY General use	E	E
Nitric, 40% Oleic Oxalic Perchloric Phosphoric	E	PEEE	Calcium chloride, sulfate Magnesium chloride, sulfate. Potassium chloride, sulfate. Sodium chloride, sulfate	E	E E E	STEEL INDUSTRY Sulfuric acid pickling Hydrochloric acid pickling H:SO ₄ -HNO ₃ pickling	E	EEF
Picric Stearic Sulfuric, 50%	E	EEEEEE	Chlorine, wet	E	E	TEXTILE INDUSTRY General use	E	E
Sulfuric, 70%	E	EZZ	Sulfur dioxide, dry Sulfur dioxide, wet	E	EEE	FOOD INDUSTRY General use	E	E
Mixed Acids 57% H ₂ SO ₄ 28% HNO ₂	E	F	ORGANIC MATERIALS	F	N	Dairies MISCELLANEOUS INDUSTRIES	E	E
ALKALIES			Alcohols, methyl, ethyl	N	N	Plating Petroleum	E	E
Ammonium hydroxide Calcium hydroxide Potassium hydroxide	E	ZEZ	Benzene Carbon tetrachloride Chloroform	N	222	Tanneries Oil and Soap	E	E
Sodium hydroxide	F	N	Ethyl Acetate		N	Water and Sewer	E	E

RATINGS:

E—No attack.
G—Appreciably no attack.
F—Name attack but usable in some instances.
P—Attacked—not recommended.
N—Hadly attacked.
C—Cold—7: F
H—Hot—3:40 F.

RESISTANT MATERIALS)

Cleveland Meeting



FULL program that comprises five symposia, two panel discussions, three sessions devoted to general papers, and plant inspection trips will feature Forty-fifth Annual Meeting of A.I.Ch.E. to be held in Cleveland, Ohio, Dec. 7-10, 1952. In addition to the technical program, there will be a ladies' program, entertainment, presentation of awards and the annual business meeting. Headquarters for the meeting will be at the Hotel Cleveland and some of the events will be held at the Carter Hotel. Registration will be at the Hotel Cleveland from 1:00 to 7:00 P.M. on Sunday, Dec. 7, and from 9:00 to 5:00 on Monday through Wednesday, Dec. 8-10.

Panel Discussions

The program starts on Sunday afternoon with a panel discussion of the problems of the local sections. Because the welfare of the national organization depends so much on the strength and activities of the local sections, it is important that the problems of the local sections be given due consideration.

A second panel discussion on professional counseling has been scheduled for Monday evening from 7:30-10 P.M. A group of experienced chemical engineers will be on hand to talk over ways and means of attaining effective professional counseling. This program is being arranged by the Professional Guidance Committee and will be initiated by a talk entitled "At the Threshold of an Engineering Career," by S. D. Kirkpatrick.

Awards Banquet

A highlight of the nontechnical part of the program will be the Awards Banquet on Tuesday evening. There will be an outstanding speaker, and the annual awards for achievement in chemical engineering will be presented.

Awards

Professional Progress Award. The fifth presentation of this award will be made at this year's hanquet. Sponsored by the Celanese Corporation of America, this award is made in recognition of outstanding progress in the field of chemical engineering leading to the betterment of human relations and circumstances. The Awards Committee of A.I.Ch.E. selects the recipient who will receive \$1000 and a certificate. Last year's award winner was C. G. Kirkbride, of Houdry Process Corp.

William H. Walker Award. The purpose of the Walker Award is to stimulate interest in improving quality, clarity of expression, and practical utility of contributions to the literature of chemical engineering. It has been awarded annually since 1936. The recipient must be an author or coauthor of an outstanding paper published by the Institute during the preceding three years. The 1951 award winner was R. H Wilhelm, of Princeton University.

The Junior Member Award. Similar in purpose to the Walker Award, the Junior Member Award is presented annually to a Junior member of A.I.Ch.E. The award winner in 1951 was C. R. Wilke, of University of California.

Institute Awards—A. McLaren White and Student Contest Problem. Three prizes have been given annually since 1932 to the winners in the Annual Student Contest for the best solution to a problem in chemical engineering. Competition for the prizes is conducted under the direction of the Committee on Student Chapters. Last year's first place winner was K. W. Rausch, Jr., of Yale University.

Technical Program

The three sessions on general papera in the technical program will cover several aspects of unit operations, industrial processes, patents and waste disposal. In order to provide a comprehensive coverage of certain topics, five symposia have been scheduled.

Student Program

Ten schools having departments of chemical engineering are within easy driving distance of Cleveland. The anticipation of a good student attendance at the meeting has resulted in the scheduling of a student program running concurrently with the technical program. Members of the Institute are welcome to attend these student meetings.

A. J. Teller, Fenn College, has arranged a program of student papers for Monday and Wednesday morning and an informal counseling program for Tuesday afternoon. A number of experienced engineers will be present to discuss problems with the students.

Monday Afternoon

How to Choose Your Employer—F. R. Fisher, Sinclair Research Laboratories, Chairman

Technical Program on page 32

(Text continued on page 39)

TECHNICAL PROGRAM

Sunday, Dec. 7, 1952 3:00-5:00 P. M.

Panel Discussion on Local Sections, arranged by C. E. Ford, Local Sections Committee.

Monday, Dec. 8, 1952 2:00-5:00 P. M.

(2 simultaneous meetings)

General Technical Program

The Growth of the Chemical Industry in Cleveland.—C. F. Prutton

Economics of Acetylene by the Wulff Process.—T. Weaver

Carbon Dioxide Absorption by Hot Potassium Carbonate Solutions.— H. E. Benson

The Manufacture and Distribution of Carbon Dioxide.—H. A. Sommers

The Historical and Legal Background of Patent Rights. - H. J. Krase

What the Chemical Engineer Should Know About Patent Laws of the U. S.—P. L. Young

Symposium—Applied Thermodynamics

Partial Moial Enthalpies of the Lighter Hydrocarbons in Solution with Other Hydrocarbons. — A. Papadopoulas, R. L. Pigford, and L. Friend

Heats of Mixing of Liquids. - C. C. Tsao and J. M. Smith

Thermodynamic Properties of Ternary Hydrocarbon Mixtures. — J. M. Nelson and D. E. Holcomb

Light Hydrocarbon Vapor-liquid Distribution Coefficients. Pressure temperature - composition Charts and Pressure - temperature Nomagraphs.—C. L., DePriester

Convergence Pressures in Hydrocarbon Vapor-liquid Equilibria.— S. T. Hadden

7:00-10:00 P. M.

Professional Guidance Committee

See page 31, News Section

Tuesday, Dec. 9, 1952 9:30 A. M.-12:00 M.

(2 simultaneous meetings)

Symposium—Modern Statistical Methods in Chemical Engineering

Experiments With Many Factors.

Making One Observation Do the Work of Two.—W. J. Youden

Statistics Training for Chemical Engineers.— H. M. Smallwood

Symposium-High Pressure

Operating Problems in Ammonia Synthesis.—A. V. Slack, H. Y. Allgood, and H. E. Maune

Bench Scale Equipment for Reactions at High Pressure.— A. M. Whithouse, P. L. Golden, R. W. Hiteshue, and E. L. Clark

Telemeric Reactions of Ethylene and Alcohols.—E. R. Gilliland and R. J. Kallal

2:00-5:00 P. M.

(3 simultaneous meetings)

Statistical Methods

An Industrial Experiment Designed to Evaluate Several Sets of Constants and Several Sources of Variability.—C. Daniel and V. W. Vaurio

The General Theory of Experiments Designed to Evaluate Several Sets of Constants and Several Sources of Variability...-H. Scheffe

Some Examples of the Use of Statistics in Heavy Chemicals Manufacture.—E. P. Foster

High Pressure

The Use of Radioactive Tracers for Continuous Analysis Under High Pressure.—H. G. Drickamer, K. D. Timmerhaus, and L. H. Tung

Fugacities in Gaseous Mixtures.— C. O. Bennett

The Thermal Conductivity of Gases Under High Pressures.—J. M. Lenoir, W. A. Junk, and E. W. Comings

The Thermal Conductivity of Nitrogen Ethylene and Carbon Dioxide Ethylene Mixtures Under High Pressures.—W. A. Junk and E. W. Cominas

General Papers

Prediction of Radical Heat-transfer Rates in Packed Beds Through Which Gases Are Flowing. — W. B. Argo and J. M. Smith

Effect of Pressure on Evaporation Rate of Drops in Gas Streams.— R. D. Ingebo

Flow Through Irrigated Dumped Packings—Pressure Drop, Loading, Flooding.—M. Leva

Mass Transfer Between Immiscible Liquids in Continuous Flow In An Agitated Chamber.— A. E. Karr

Process Design and Specification of Pumping Equipment.— R. L. Jacks

6:30 P. M.

Awards Banquet

Wednesday, Dec. 10, 1952 9:00 A. M.-12:00 M.

(2 simultaneous meetings)

Symposium—Human Relations

The Engineer's Stake and Status in Human Relations.—R. L. Demmerle

Why Does He Succeed or Fail With People? -R. S. Schultz

How to Build Working Harmony Among People,—Paul Pigors

Effective Language—The Catalyst of Human Relations.—Phillip Swain

Luncheon Address

Taking a New Look at the Engineer's Work. -F. H. Kirkpatrick

Symposium—Filtration

The Concept of Filtration Resistance of Compressible Materials.— W. L. Ingmanson

The Role of Porosity in Filtration: Part I.-F. M. Tiller

Resistance and Compressibility of Filter Cakes.—H. P. Grace

The Prediction of Filtration Operations: Part I, Conclusions for Some Permeability Tests.—C. G. Lindquist and J. J. Youle

2:00-5:00 P. M.

(2 simultaneous meetings)

General Papers

Performance Characteristics of a Liquid-liquid Spray Tower: I, Column-operation Studies; II, Area and Volumetric Heat-transfer Coefficients.—L. Garwin and B. D. Smith

Liquid-film Thickness and Velocity for Centrifugal Spray Nozzle.— M. Doumas and R. Laster

Countercurrent Ion Exchange with Trace Components.—N. K. Hiester, E. F. Fields, R. C. Phillips, and S. B. Radding

Performance Characteristics of a Podbielniak Centrifugal Extractor. -N. Barson and G. H. Beyer

Symposium—Filtration

Mechanism of Washing of Filter Cakes.—B. F. Ruth

An Improved Method for the Acid Decomposition of Certain Silicates. -W. J. Huff and E. A. Gee

Preparation and Treatment of Slurries for Filtration.—C. A. Wolbach

Filtration of Aluminum Hydroxide with Filter Aid.—C. D. Luke

Sluicing Pressure Leaf Filters.— -E. A. Ulrich

Replaceable Micronic Filters, A New Tool for the Chemical Engineer.— E. Kanc

Liquid-flow Rates and Electrokinetic Effects in Graded Beds.—C. J. Dobratz

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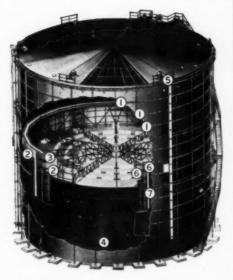
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Get-acquainted party in the Grand Ballroom of Palmer House.

Reviews of Engineering Achievements Mark Chicago Meeting



Irving Leibson

CENTENNIAL celebrations brought out engineers in full strength in Chicago last month, when more than sixty engineering organizations helped the American Society of Civil Engineers celebrate its one-hundredth anniversary. The A.I.Ch.E., catching the spirit of the celebration, turned out in record numbers and for this type of meeting, hung up a record of attendance. The attendance record was 1221, the previous high of 912 having been held by the Cleveland

meeting of May, 1948. Though the Centennial had many programs scheduled at the same time, the chemical engineers stayed close to the headquarters hotel, the Palmer House, and each technical meeting was well attended.

The plan of the Chicago meeting was strictly informal, with no luncheons or banquets scheduled. Free time was emphasized, and the only after-hours event was a Yankee-White Sox baseball game.

as a Yankee-White Sox baseball game. Diameter on Mass Transfer in Liquid-The contest for the best-presented (Continued on page 36)



Left: Symposium on mixed bed ion exchange; (I. to r.) S. F. Alling, Hungerford & Terry; M. E. Gilwood, The Permutit Co.; J. F. Wantz, Illinois Water Treatment Co.; R. F. Schulze, Culligan Zeolite Co.; D. R. Babb, Elgin Softener Co.; J. Thompson, Rohm & Haas Co., at the microphone.

paper was difficult to judge since many

fine presentations were given and the

judges were carried right down to the

final paper, deciding that Irving Leibson

of the Humble Oil & Refining Co. was

adjudged to have given the best platform

demonstration. Dr. Leibson was co-

author with Robert B. Beckmann, of

Carnegie Institute of Technology, on

"The Effect of Packing Size and Column

Right: Hard-working committee heads; standing (I. to r.) Tom Matthews, Pure Oil Co., Exec. Comm.; George Bailie, Wurster & Sanger, Inc., Exec. Comm.; E. N. Mortenson, Swift & Co., Exec. Comm. and chairmon of Chicago Section, A.I.Ch.E.; C. F. Gerald, Universal Oil Products, Press Room; H. H. Newman, Swenson Evaporator Co., Exec. Comm.

Seated (I. to r.) R. S. McDaniel, Standard Oil Co. (Ind.), chairman, Registration Comm.; D. A. Smith, Swenson Evaporator Co., chairman, Exec. Comm.; and D. A. Dahlstrom, Northwestern Technological Institute, chairman, Technical Program Comm.





C. F. Kettering



L. M. Le Baran



P. D. V. Manning



J. H. Rushton



E W lawi



R. E. Zinn



T. W. Matchetti



R. C. Gunness



G. Gutzeit



H. F. Johnstone



J. A. Duffie



T. Vermeulen



W. C. Edmister



H. Dohlberg, Jr.



H. Corley



K. H. Hochmuth



N. Gilliatt



E. G. Scheibel



B. W. Gamson



K. Kommermeys



G. Thedes



E. J. Landis



C. S. Velz

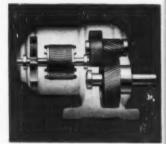


W. I. Burt

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CHICAGO MEETING

(Continued from page 34)

Liquid Extraction."

Plant tours, always a feature of Institute meetings, came off as scheduled, with inspection of the following: Abbott Laboratories, International Harvester Co., Swift & Co., Central Scientific Co., S. C. Johnson & Sons, Standard Oil Co., Corn Products Refining Co., G. D. Searle & Co., Universal Atlas Cement Co., Western Electric Co., The Glidden Co., Sears Roebuck & Co., Sherwin-Williams Co., Sinclair Research Laboratories, and Armour and Company, chemical division.

Technical Papers

In cooperation with the Centennial of Engineering, the Chicago program began with an all-day review of progress in recent chemical engineering developments. Called "The Chicago Symposium," it illustrated the contributions of the Chicago area to chemical engineering. The symposium, under the cochairmanship of Paul D. V. Manning. vice-president of International Minerals & Chemical Corp., and Dr. Harry Mc-Cormack, editor of Putman Publishing Co., featured talks on "Chemical Engineers in the Packing Industry," by Victor Conquest, vice-president of Armour and Co.; "The Fluidized Solids Technique in the Petroleum Industry," by R. C. Gunness, assistant general manager of manufacturing, Standard Oil Co. (Indiana); "Industrial Carbon," by Bernard W. Gamson, director, research and development, Great Lakes Carbon Co. A talk was given on "Mixing-Present Theory and Practice," by J. Henry Rushton, director, department of chemical engineering, Illinois Institute of Technology, and I. Milton LeBaron, director of laboratories, research division, International Minerals & Chemical Corp., talked on "Particle Sizing with Special Reference to Phosphate Concentration Operations"; C. S. Velz. chairman, department of public health statistics, University of Michigan, discussed "Stream Self-Purification": Prof. R. E. Zinn, department of chemical engineering, Northwestern University, gave a paper on "Applications of Low-Temperature Carbonization"; talks were given on "The Art of Material Handling Equipment," by E. A. Wendell, sales manager, Caldwell plant, Link Belt Co., Chicago, Ill., and "Recovery of Sulfur Dioxide from Waste Gases," Prof. H. F. Johnstone, chairman, department of chemical engineering, University of Illinois. The afternoon symposium had as cochairmen, W. E. Brinker, assistant chief engineer, Corn Products Refining Co., and Prof. L. F.



FRS SPREE

Stutzman, chairman, department of chemical engineering, Northwestern University.

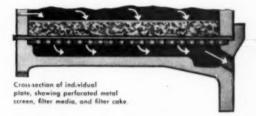
An outstanding symposium on "The Distribution of Chemicals" was on the program under the cochairmanship of Henry Dahlberg, Ir., supervisor of technical economics of the International Minerals & Chemical Corp., and R. M. Lawrence of the general development department, Monsanto Chemical Co. This symposium, part of the Institute's general plan to emphasize also nonmathematical problems in the chemical field which affect chemical engineers, covered transportation, packaging, and the selling of chemicals. Speakers were E. J. Landis, International Minerals & Chemical Corp.; Don Ballman, general sales manager, Dow Chemical Co.; Neill Gilliatt, account executive. McCann-Erickson, Inc.; and Hoyt Corley, manager, new products department. Armour and Co.

Several agreeable compliments were paid the chemical engineer by Victor Conquest in his talk in the opening symposium on "Chemical Engineers in the Packing Industry." Said Dr. Conquest, ". . . some of the operations of the meat packing industry, particularly the handling of by-products, take on the complexion of a chemical business. This type of operation is tailor-made for the chemical engineer. . . . For example, waste recovery and disposal, drying processes, high vacuum work, contact evaporators, and spray driers are but a few of the topic areas in which chemical engineers have been almost indispensable. In the course of making these developments some very useful inventions have been made."

"Further," he added, "one of the hardest jobs of our chemical engineers is to convince equipment builders that certain specifications are absolutely necessary. One instance that I remember had to do with an all-stainless unit that had to be stainless for the protection of the material being handled. When the unit was ready to run, it was equipped with brass valves, and the builder was annoved at being made to change them." Mr. Conquest further gave credit to chemical engineers for the design of the original equipment to distill fractionally fatty acids. The final demonstration of the worth of the idea came, he revealed, when the chemical engineer built a small unit by himself.

Some of the difficulty of adapting the art of handling materials to the chemical field was brought out in a talk by E. A. Wendell, of the Link Belt Co. "The chemical industry poses problems that tax the resourcefulness and ingenuity of materials handling engineers to a

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greater extent than almost any other industry. Many of its processes are relatively new and some are bewilderingly complex and the success of the materials handling system depends upon a thorough knowledge of the materials to be handled. In the chemical industry," he continued, "these characteristics differ widely." He indicated that sometimes they defy comparison with other materials for which the materials handling art has been developed. Adequate study and observation may not be possible because of secrecy, or, ". . . because sufficient quantities are not available during the design stages. This sometimes makes it necessary for the materials handling engineer to approach such problems virtually blindfolded."

A description of the application of the technique of fluidization to the production of SO2 for use in the sulfite pulping process of the pulp and paper industry, was given by R. B. Thompson, assistant manager of The Dorr Co. Essentially, the paper described the use of the fluidized technique to utilize pyrite and pyrrhotite for the SO2 supply. The technique, according to Thompson, enables the use of these materials to produce a gas of about 90% of the theoretical maximum obtainable from these materials. In the case of pyrite a theoretical maximum gas is 161/2% SO2, while pyrrhotite would give a theoretical yield of 14.4% gas. By using a fine water spray into the heart of the reactor, it is possible, Mr. Thompson said, to prevent the sintering of the raw materials into solid iron oxide. The reaction takes place at 1650° F. which, if uncontrolled, would sinter the fine particles into larger particles, thus destroying the fluidization advantages. The unit, according to Thompson, enables an important source of sulfur to be tapped for the production of SO2 gas, without putting a drain on our reserves of elemental sulfur. It was further revealed that within a short period, eight different paper mills and four sulfuric acid manufacturers will be using this type of equipment to supply major portions of their SO2 needs.

In a report of an extensive and continuing study on spray-drying materials, 1. A. Duffie of the Office of Naval Research, and W. R. Marshall, Jr., of the University of Wisconsin, reported on the factors they had uncovered in spraydrving experiments. They reported in conclusion that the bulk density of spraydried materials decreased with an increase in drying air temperature, ascribed to an increased tendency of the particles to expand on drying and to earlier formation of vapor-impervious

films on the drop surface.

CLEVELAND MEETING

(Continued from page 31)

- 2:00 What Students Look For In An Employer—John Schlueter, director of placement bureau, Michigan State College
- 2:30 Advantages of Working in a Big Corporation—Bruce J. Miller, personnel administrator, Linde Air Products Co.
- 3:00 Advantages of Working in a Small Company—L. A. Hatch, vice-president research and product development, Minnesota Mining and Manufacturing Co.
- 3:30 The Evaluation of Technical Enterprises—R. G. Woodbridge, III, senior industrial specialist, New York Life Insurance Co.
- 4:00 Market Situation for Chemical Engineers—Ewan D. Clague, Commissioner of Labor Statistics, U. S. Department of Labor
- 4:30 Discussion of all papers



Standing left to right: J. F. Revilock, Finance Committee, and E. R. Young, Publicity. Seated left to right: C. O. Miller, General Chairman, and C. J. Dorer, Committee Secretary.

Tuesday Morning

Unusual Employment Opportunities for Chemical Engineers

- 9:00 Introductory remarks—W. E. Gift, Tennessee Eastman Co., Chairman
- 9:15 It's Your Move—H. G. Donnelly, chairman, A.I.Ch.E. Professional Guidance Committee
- 9:45 The Chemical Engineer in Safety Engineering—Mathew M. Braidech, director of research, National Board of Fire Underwriters, New York
- 10:15 The Chemical Engineer in Purchasing — David S. Flanders, manager, purchasing division chemicals and pigments department, B. F. Goodrich Co.
- 10:45 The Chemical Engineer in Patent Law-W. C. Asbury, Chairman of A.I.Ch.E. Patent Committee, Vice-President Standard Oil Development Co.
- 11:15 Question period, round-table discussions.

Plant Trips

Selected to permit visitors to view a good cross section of the chemical industry in the Cleveland area, the following list of interesting or unusual plant trips has been scheduled for this meeting. All trips are scheduled in the afternoon in order to minimize conflicts with the technical meeting. Only citizens of the U.S.A. may visit the Lewis Flight Propulsion Laboratory of National Advisory Committee for Aeronautics, and these persons must submit their requests by November 25 in order to permit security clearance to be made. Preregistration for these plant trips may be done on the cards accompanying the printed program.

Monday, Dec. 8: Glascote Products, Inc. Glidden Co., Goodrich Research Center Harshaw Chemical Co. Lewis Flight Propulsion Laboratory, NACA.

Tuesday, Dec. 9: Glascote Products, Inc. Goodrich Research Center Industrial Rayon Corp. Lewis Flight Propulsion Laboratory, NACA Standard Oil Company of Ohio

Ladies' Program

The ladies who are registered for the meeting are invited to attend the social hour on Sunday evening and the Awards Banquet on Tuesday. In addition, a special program has been arranged for them by Mrs. C. E. Ford and Mrs. W. I. Burt, eochairmen.

Beginning with a coffee hour at 10:00 A.M. on Monday, the ladies will then attend a luncheon with Dorothy Fuldheim, television commentator, as the guest speaker.

On Tuesday morning, the group will visit the Cleveland Health Museum. first in America. Special attractions at this unusual museum will include a 15min. demonstration by "Juno," the famous talking transparent woman. In the "Wonder of New Life" room is the renowned Dickinson collection of life-size, sculptured birth models. Many threedimensional exhibits showing the means and advantages of maintaining good health will be seen. Among these are: "The 1950 Census on a 10-Finger Basis," a dramatic pictorial presentation; "Rewards of Alertness," an exhibit on cancer; and the special exhibit for December, "Testing the Drinking Driver," on loan from the American Medical Association.

A luncheon and tour of the Lighting Institute at the world famous Nela Park are scheduled for Tuesday. Both engineers and housewives will be interested in this trip which will demonstrate the newest developments in light-

ing. Specific exhibits include the horizon house, store, sun deck, office-school center, and the kitchen. The institute is open to the public on Tuesday evening which will give some men a chance to see the exhibits.

Entertainment

The lighter side of the meeting starts with a party on Sunday night in the Ballroom and Redroom of the Hotel Cleveland. Here is an opportunity to see old friends and meet new ones while enjoying refreshments and light entertainment. Tickets will be issued during registration.

Because of a full technical program, Monday night has been left open except for the panel discussion on professional counseling. A list of theatre productions and other events in Cleveland will be available at the information desk to



Left to right: A. J. Teller, Chairman, Student Program Committee, R. L. Savage, Chairman, Technical Program Committee.

serve as a guide for the evening's activities. Cleveland stores are open until 9:30 P.M. on Monday nights so that some early Christmas shopping will be possible or you can obtain a "peace offering" without interrupting your attendance at the regular program.

HOW IS YOUR LOCAL SECTION DOING?

Having problems in keeping up attendance? Arranging programs? Getting speakers? Getting publicity? Collecting dues?

Discussions of these and other mutual problems will be the purpose of the panel discussion that has been arranged by C. E. Ford, chairman. Local Sections Committee. Plan to attend this meeting Sunday, Dec. 7, from 2-5 P. M.

The First Hundred Years

As stated on the editorial page, "C.E.P." has lifted from some of the many papers given at the recent Engineering Centennial, paragraphs expressing engineering accomplishments, hopes, and ideals. Though the Engineering Centennial is now history, "C.E.P." hopes to keep alive the spirit of that celebration here and in ensuing months.

The Stamp of Education

Most of the criticism that has been directed at the colleges in the past is due to the lack of the so-called humanities. The schools have picked up this challenge and there is considerable improvement in the teaching of the subject. It is understood that the schools cannot begin to cover the material in four years and we, in industry, must continue this educational process.

There are many subjects, for which the engineer is not ready during his formative years . . . , that he can take with appreciation only after he has had considerable experience and after he has matured. It is most important then that industry continue to work toward taking more and more responsibility in the development of manpower. . . . We, in industry, cannot expect our present educational system to turn over to us highly qualified engineers who have a thorough understanding of our own particular business, who have a basic understanding of the place of American industry in the future of America, who are diplomats, who can assume responsibility for complicated labor relations and who have many other traits necessary for leadership-all this in a package that is only 21 years old.

Education in Industry Maynard M. Boring

2 Good books were being printed and widely disseminated. The minds of men were as great as they have been in any age—and once they were free to think, they thought great thoughts that brought some of the greatest advances in all time.

Before the eighteenth century, training for engineering was by apprenticeship. If you can get the right masters and apprentices together there is no better method; but it is not geared to handle large numbers of students. Schools for engineers grew out of the need for more well-trained men than the apprentice system could provide. It was the French who led in the development

of engineering as an art-science in schools of higher learning, and other Europeans and Americans soon followed their lead.

> History of Engineering Education Frederic T. Mavis

As an educational center the engineering college is a component in a flow circuit. Knowledge flows outward through the undergraduate student, the graduate student, faculty consultation, faculty texts, and technical publications. The channels consisting of the newspaper, house organ, radio, and television have not been exploited adequately. However, within the next generation the professional engineer will utilize more effectively these media of communication.

But the return flow path from industry and from the field to the engineering school has not been established as a conscious effort. Catalogs, advertisements, house organs, sectioned and working models, often available to the faculty and student, serve as a partial return path.

Looking Ahead in Engineering Education L. M. K. Boelter

The Engineering Environment

engineering profession, ably supported by licensing requirements, reserves for itself those levels of professional activity which require the peculiar type of training that the engineer receives in college. While the engineer seeks to multiply his capacities for handling the highest levels of professional competence he must be aware that he can increase his own productivity by assigning responsibilities for many technical assignments to those with less training than a full engineering curriculum. It is the responsibility of the engineer therefore to guide and direct the subprofessional type of training and the subprofessional technician in order that the engineer may be increasingly useful in his professional capacity.

The Technical Institute—Its Relation to Engineering
Education and Trade Training
C. W. Beese

2 If ever I wanted to be a cheer leader, it has been this week while reading what so many specialists, engineers, and other eminent men have been saying here in Chicago. These top authorities are not scared of the future. They are eager to prove what science and industry can do to benefit mankind. They have the vision, and the faith, as their predecessors did, to go on bettering the conditions and things and methods of yesterday.

Man Must Have Food Clarence Francis

* When we say a man thinks in English or in German or in mathematics, we mean exactly that. Language is a tool for thinking as well as for expression, and the engineer uses at least three languages for these purposes: English or his native tongue, mathematics to an ever-increasing degree, and graphical presentation or drawing.

Contemporary Demands on Chemical Engineering Undergraduate Curricula Geo. Granger Brown

What Manner of Men

Success comes to the engineer who practices being a student throughout his life span. Ambition urges him to continue with self-education by affiliation with his professional engineering societies, participation in community affairs and through technical reading.

Education—Engineer's Lifetime Job Ralph L. Goetzenberger

The ability to take the responsibility for a solution based on incomplete data and thereby create a new process or a new design is the outstanding characteristic of the engineer.

Geo. Granger Brown

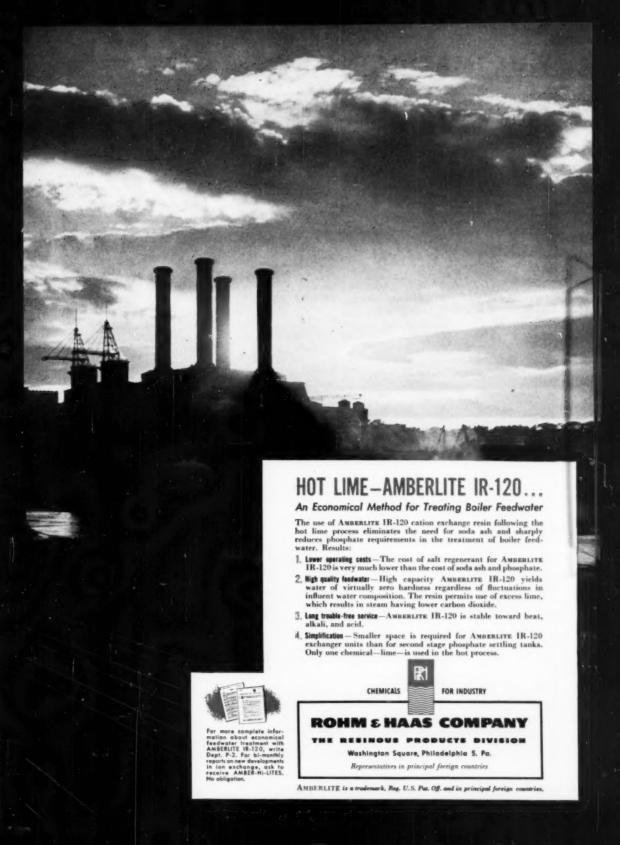
Engineering-Its Definition

Engineering in its broadest terms is the art of directing the great sources of power in Nature for the use and convenience of man.

Whether Cain was the first womanborn civilized man is not important; but the legend that he constructed the first engineering works of civilized man by building a city is interesting.

Frederic T. Mavis

(More Excerpts on page 48)



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England - J. Blukeborough & Sons, Ltd., Brighouse, Yorks. . France - Premafrance, Paris



DATA SERVICE

BULLETINS

- 1 . ENGINEERING HANDBOOK, For design engineers, from Plastic and Rubber Products Co. a loose-leaf engineering handbook. Covers data on Parco O-Rings.
- 2 . PROCESS EQUIPMENT. Precisionfabricated equipment for chemical processing industries, such as heat exchangers, process piping, fittings, refractories, etc., described in a new bulletin from the M. W. Kellogg Co.
- 3 . POMONA PUMP. A new Pomona "Little Chief" pump, applicable to lifts from 10 to 250 ft., capacities 300 to 9000 gal./hr. and constructed for wells as small as 4 in. in diam. By Fairbanks, Morse & Co. Bulletin describes in detail construction, applications, etc.
- 4 . WET PIT PUMPS. Two similar but functionally different wet pit pumps are described by Yeomans Brothers Co. in new bulletin. Gives construction features, control apparatus, selectivity charts, installations, etc. Also introduces Lubri-Vac, a new system providing continuous lubrication of pump bearings.
- 5 . CONTROL VALVE DESIGN. New Techniques in Control Valve Design is title of 16-page technical bulletin from Conoflow Corp. Gives cutaway construction views, discusses present and future design, advantages, etc.
- 6 . FLEXIBLE METAL HOSE. A new catalog covering complete range of products by Flexonics Corp. Includes corrugated flexible metal bose, convoluted-hose types, and stainless flexible metal hose. Detailed information on sizes, types and installations.
- 7 . INDUSTRIAL INSULATIONS. Baldwin-Hill Co. in a new 20-page illustrated catalog describes insulating materials covering a range of -150° F. to 1800° F. Pipe covering, insulating cement, block, felt, etc., shown with thermal-conductivity graphs and

heat-loss charts. Applications described.

- 8 ELECTRODEPOSITION. Salvaging worn or overmachined parts by plating to build up surface reviewed in detail, by International Nickel Co., Technical factors discussed. Also advantages of nickel plating contrasted with heavy chromium
- 9 . UNDERCOATING. A new industrial undercoating is announced by Minnesota Mining & Mfg. Co. Coating is a tough, sprayable, black-asphalt material for use in corrosion control, weather protection, sound deadening. Adheres to most materials, corrosion resistant, dries rapidly.
- 10 . CASTING RESINS. A new line of casting resins and potting compounds for civilian and military use in embedment of circuits and for hermetic-scaling protection against moisture, etc. Low shrinkage, good adherence to metal leads, etc. Negligible corrosive effects. Carl H. Biggs
- 11 . LUBRICANT. Where heat and friction problems are present Colgra Superfilm, a 100% pure oil additive is friction and heat-reducing. Contains no chemicals, graphite or other ingredients. Film strength ranges from 12,000 to 15,000 lb. Clover Co.

- 12 . INDUSTRIAL CHEMICALS. Commercial Solvents Corp.'s new bulletin lists its line of industrial chemicals such as alcohols, aminohydroxy compounds, nitroparaffins, esters, etc. Chemical formulae, molecular weight, gravity, etc., given.
- 14 BRIGHTON KETTLES. For those with difficult problems in mixing of rubber and paint, Brighton 500-gal. steel, steam-jacketed kettles; feature double-motion agitators providing smoothness and consistency. Brighton Copper Works, Inc.
- 15 . ANILINE SALT. American Cyanamid Co. announces new aniline salt for use in printing black. Lists complete line giving components and other details.
- 16 . NONAQUEOUS ION EXCHANGE. Available from Fisher Scientific Co. in laboratory quantities, Amberlite IR 112 (H) up to 25 lb. Analytical grade, specially purified, porous for use in treatment of nonaqueous fluids, recovery of large cations from waste and process solutions, operation of hydrogen cycle, etc.
- 17 . SLY DYNACLONE. A new dust filter for continuous processes where uniform suction is desired at all dust points, announced by W. W. Sly

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DATA SERVICE

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18 • DRYERS. Thirty different types of Standard Hersey dryers suitable for food processing, drying of fish products, oil refining, rendering, etc., are photographed and discussed in a new bulletin from Standard Steel Corp.

19 • TURBIDITY RECORDER. Now available from Ess Instrument Co. a bulletin on the new electric-eye turbidity recorder. Measures exact light cut off by undissolved particles. Bulletin gives operating principle, range of application, etc., together with technical illustrations.

20 • BOILER TUBE CORROSION.
Tubular Products Division Babcock
& Wilcox Co. leaflet on how to avoid
boiler tube corrosion. Study states
causes of boiler tube failures, proper
operating and maintenance procedures, how to reduce retubing, etc.

21 • POLYPHASE INDUCTION MOTORS. Both squirrel-cage and wound-rotor induction motors, available in open and protected dripproof, splashproof, and other housings described and illustrated in bulletin from The Electric Products Co.

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22 • SCREW PUMPS. Sier-Bath Gear & Pump Co. reply sheet for answers to pump problems.

23 • VARIAC CONTROLS. The full line of Variac Motor speed controls is illustrated in bulletin from General Radio Co.

24 • BOILER TUBE DATA BOOK. A new technical data book available from Babcock & Wilcox Co. on electric-resistance-welded steel boiler tubes. Weights, diameters, maximum pressures, etc.

25 • SHELF STORAGE. For economy in shelf-storage space Frick-Gallagher Mfg. Co. explains its Rotabin units of various types and sizes in a new bulletin.

26 • SURFACE ACTIVE AGENTS, Issued by E. F. Houghton & Co. new bulletin on surface-active agents for the metal-working industry.

27 • PROCESSING AND HEAT TREAT-ING EQUIPMENT. The Pressed Steel Co.'s catalog covering engineering data on 270 types of bubble caps and risers for fractionating towers and stills. Illustrations of equipment, tubes, welded tubing assemblies, etc. Available in complete range of heat and corrosion-resistant sheet alloys. Tubes in sections to % in., diam-

eters to 60 in., temperatures to 2200° F.

28 • SPECTROPHOTOMETER. Performance and construction of a new double beam recording infrared spectrophotometer described in bulletin from Perkin-Elmer Corp. Includes background sections on infrared spectroscopy and optical null principle employed. Descriptions as well as performance data and accessories.

29 • PIPE-CUTTING PANTOGRAPH. New with Vernon Tool Co., Ltd., is a catalog-bulletin on its pipe-cutting Pantograph. Produces straight or beveled cut-offs of exact fit, cuts any intersection or length pipe, portable, one-man operation. Illustrated.

30 • BROWN VALVES. Complete line of Brown Valve Division Vernon Tool Co., Ltd., swing check valves described and illustrated. Data sheet gives types, pipe size, weight, etc. Also available complete lines of cast steel globe, steam throttle and angle valves.

31 • STANDARDS BULLETIN. New standards bulletin on end preparation and internal machining for machine backing rings for butt welds. Supersedes earlier standards. Five other standards of interest to designers, contractors and users of pressure piping available also from The Pipe Fabrication Institute.

32 • SALCONE NOTEBOOK. Dow Corning Corp. notebook on 200 straight-chain silicone polymers. Defoamers and polish ingredients, release agents, dielectric, damping medium and paint additives. Full description applications. Chemical structure boiling and freezing points, volatility, etc.

33 • NAGLE PUMPS. Catalog describing pumps from Nagle Pumps, Inc.

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35 • EJECTORS. For vacuum service and refrigeration a line of steam jet ejectors described in bulletin from C. H. Wheeler Mfg. Co. Cutaway views, graphs, conversion tables and other pertinent data.

36 • LINDE-FRAENKL PROCESS. Available now to industrial users in the U. S., the Linde-Fraenkl oxygen and other low-temperature separation processes, from Blaw-Knox Co. A 24-page booklet gives all pertinent details. Includes section on thermodynamic data on air, oxygen and nitrogen.

37 • AEROFIN COILS. Aerofin Corp.'s bulletin file on standardized heating surface, temperature rise tables at air velocities above 800 ft./min. Amply illustrated, gives condensation, performance tables, etc.

38 • 39 • STEAM TRAPS AND SELECTORS. (38) Yarnall-Waring Co. bulletin on steam traps for power plants, steam processes, etc. (39) Covers trap selector giving uses, together with tables on pressures, capacities and sizes.

40 • ALLOY STEEL CHART. Chart shows chemical analysis for 70 Military, Army, Navy, Aeronautical, and Federal specifications. Also listed are specified forms (sheets, bars, tubing, etc.). From Peter A. Frasse & Co., Inc.

41 • MICRO SWITCHES. New catalog of snap-action switches from Micro division Minneapolis-Honeywell Regulator Co. Covers heavy-duty precision limit switches, explosionproof and splash-proof switches, etc. Dimensions, mechanical and electrical characteristics, electrical capacities, etc.

42 • PREHEATING OVENS. Portable preheating and drying ovens by Despatch Oven Co. for the plastics field. Used in compression, transfer and injection molding. Dries from 600 to 1000 lb./day. Automatic control.

43 • FACING ALLOYS. Wall Colmonoy Corp. detail line of hard-facing alloys both nickel and iron base, as well as Sprayweld process, of application. Combines metal-spraying and welding. Guide for typical applications.

44 • AL-CR PAINT. A decorative aluminum-chromium preservative for all exterior and interior surfaces. Rust-proof and noncorrosive. The Monroe Co., Inc.

45 • FABRICATED FITTINGS. Elbows, tees, laterals, manifolds, etc. available in carbon steel. Fabricated specials in range of 3 to 44 in. diam., walls up to ½ in. in carbon, alloy, stainless steels, Monel, Inconel, etc. Bulletin gives sizes and types. Naylor Pipe Co.

46 • CONVEYOR. A Flexmount positive-action-oscillating conveyor announced by Link-Belt Co. Can be had in any desired length from subassemblies, 8 to 18 in. trough widths. Guide to correct selection, conveyability chart, dimensions and specifications.

47 • MOLDED CUPS. Cups for pump pistons, hydraulic service, and pneumatic equipment, fabricated by The Garlock Packing Co. Bulletin covers specifications, applications, types.

48 • BOILERS. A 200 hp. Powermaster automatic boiler by Orr & Sem-

bower. Steam at 13,800 lb./hr. Burns light, heavy residual, or commercially available gas.

49 • ALLOY CASTINGS. Heat-and corrosion-resistant alloy castings for use in the cement, chemical, ceramic, oil-refining industries, as well as power plants, steel mills, etc., by International Nickel Co., Inc. A 48-page booklet with 175 illustrations of typical applications. Charts compare creep strength of various alloys, resistance to corrosion and oxidation. Tables of composition list Alloy Casting Inst. designations, Also proprietary alloys.

50 • SCALES. Howe Scale Co.'s new ball-bearing axle load scales. Built for continuous weighing of motor truck and trailer axle loads.

51 • BIN-DICATOR. An automatic bin level indication and control on all bulk materials from Bin-Dicator Co. Diaphragm materials are cloth, rubber, Fiberglas and asbestos cloth. Several types and sizes.

52 • COMPUTER. Capable of rapid solution of as many as twelve simultaneous linear equations and announced in a bulletin from Consolidated Engineering Corp. This new electrical computer reduces computation time 1/6 to 1/10, reduces operator errors, and permits employment of personnel without advanced mathematical training.

53 • CONVEYORS. For all industries requiring conveying equipment Rapistan by Rapids-Standard Co., Inc. Gravity and powered conveyors, trucks, etc., photographed and described, dimensions, special features, etc., included in new bulletin.

54 • MAGNETIC TRAPS. Eriez Míg. Co.'s permanent nonelectrical, pipeline trap removes tramp iron from liquid flow lines. Noncorrosive, of stainless steel, unaffected by high temperatures. Pressures up to 75 lb./sq.in.

- 55 COOLING TOWERS. Foster Wheeler Corp.'s bulletin on complete line of cooling towers. Describes air and water distribution, air resistance, spray loss, etc., materials of construction, uses, etc.
- 56 SILICONE RUBBER. For those with design considerations a new booklet from General Electric Co. Covers properties, available classes of silicone rubber, as well as design specifications and uses.
- 57 X-RAY TECHNIQUES. Reprinted article on X-ray technique. Also reprint on X-ray tin coating gage. Details on operation and uses. From North American Philips Co., Inc.
- 58 ELECTRIC SPRAY GUN. All metal with trigger action and extremely light weight. Suitable for many industrial applications such as spraying paints, lacquers, chemicals, oils, etc. Champion Implement Corp.
- 59 INDUCTION MOTOR. Elliott Co. describes line of outdoor splash-proof induction motors. Hp. 250-4000, 2 poles; 50-3000 hp., 4-14 poles. Ring-oiled, pressure-lubricated, or antifriction bearings. Many special features, variety of types.
- 60 HYDROTORQUE. For hydraulic positioning of valves, etc. Farris Hydrotorque Corp.'s leaflet on its line of hydrotorques. Applications in aircraft, marine, refinery, chemical and other industries. Technical details complete with diagrams.
- 101 GAGES AND VALVES. Liquid level gages, valves and specialties made by Jerguson Gage & Valve Co. Heated and cooled, non-frosting. flanged-end, etched-glass gages and some of special metals.
- 62 CONTACTS. Pocket-size, looseleaf booklet of Assembly Products, Inc., covers Sim-Ply-Trol contact meter-relays. Diagrams, list of components for circuits shown. Discussion of mounting, cleaning and servicing. Replacement parts listed.
- 63 SYNCROGEAR MOTOR. A rightangle worm geared Syncrogear motor from U. S. Electrical Motors, Inc. Bulletin in color depicts individual parts. Self-locking brake action, precise gear location are features.
- 64 DUSTUBE. American Wheelabrator & Equipment Corp. tells how

- to reduce dust problems in rubber, agricultural, chemical, ceramic, and other industries with Dustube. Bulletin available.
- 65 CARRIER AMPLIFIER. For small engineering and development laboratories, analysis and evaluation of high frequency and physical factors affecting product performance. Permits measurement of stress, strain, acceleration, displacement. Consolidated Engineering Corp.
- 66 VINSOL. Neutralized Vinsol solution used as an air-entraining agent is new with Hercules Powder Co. Folder describes advantages, production process, desirable uses, quantities to be used, etc.
- 67 COLLOIDAL GRAPHITE. New uses for colloidal graphite discussed in folder from Acheson Colloids Co. Use as a surface coating for mechanical devices and as an impregnating medium.
- 68 AIR SHIPMENTS. This particular phase of transportation in every industry discussed at length in data book from The Hinde & Dauch Paper Co.
- 69 BIFURCATOR FANS. DeBothezat fans division of American Machine and Metals, Inc., offers a revised edition of its catalog on bifurcator fans.
- 70 VACUUM DRYING. Methods of vacuum drying and complete mechanical description of rotary vacum dryers are described in a wellillustrated catalog from F. J. Stokes Machine Co.
- 71 EXTRUDERS. Two new bulletins from F. J. Stokes Machine Co. Covers Stokes-Windsor multi-screw; R.C. 100 twin screw and R.C. 200 triple screw.
- 72 JET MIXERS. Efficient machines designed specifically for jet mixing liquids and solids, for emulsifying, etc. Barrington Engineering Co. catalog.
- 73 AIR-OPERATED VALVES. From Minneapolis-Honeywell Regulator Co. double-seated diaphragm valve described in 8-page specification sheet.
- 74 ELECTRO O VANE CONTROL. Used on Brown indicating and recording pressure gauges and covered

- in specification sheet from Minneapolis-Honeywell Regulator Co.
- 75 LIQUI-JECTOR. For removal of water, water-oil emulsions and dirt from compressed air the Liqui-Jector by Selas Corporation of America.
- 76 INDUSTRIAL MAGNIFIERS. A 24-page guide on this subject from Bausch & Lomb Optical Co. for use in the laboratory, plant or office, to improve quality, cut costs and increase production.
- 77 P-R GAS BURNERS. Flame-type, used in heat processing, glass fire polishing, etc. Manufactured and described by Selas Corporation of America.
- 78 COMBUSTION SAFEGUARDS. Two protective devices used in piping systems of gas-and-air combustion systems. Bulletin SC-1006. Selas Corp. of America.
- 79 HUM-I-DRI. A moisture absorbent for industrial and residential use. New with Speco, Inc.
- 80 EXTRUSION MACHINES. Used in extruding rubber, plastics, wire and film. Screw-type. Allen Extrusion Machine Division, Industrial Ovens, Inc.
- 81 FILTER GAUGES. Builders—Providence, Inc., bulletin on mechanically operated filter gauges. Explains principle of operation for use in water works and purification processes. Instrument shows rate of flow, loss of head in feet.
- 82 KOBE TRIPLEX PUMP. Developed originally for pumping oil wells hydraulically and now applied in aircraft, rubber and steel industries. Kobe, Inc.
- 83 MOLDING MACHINES. From Hydraulic Press Mfg. Co. the story of application of hydraulics to American industry.
- 84 COIL BOBBINS. Nylon coil bobbins made by an economical high-speed, single-injection cavity-molding process and available in sizes .025 oz. and 1 in. in length. Gries Reproducer Corp.
- 85 MANOMETERS. For industrial and laboratory use differential or absolute manometers and other types of mercury-containing instruments. Bulletin from Chemiquip Company.



National Lead Company's use of Glycerine for making synthetic resins dates back over 35 years. Today, Glycerine-derived alkyds play an important part in many of National Lead's familiar "Dutch Boy" paints. They're used in exterior finishes, such as quick-drying enamels for sash and trim, and also in enamels and flat paint for interior use.

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For years, leading manufacturers of household and industrial finishes have favored Glycerine for making alkyd resins. Why? Because Glycerine-derived alkyds give them excellent package stability... improved water resistance... outstanding durability.

Glycerine-derived alkyds improve color retention and film toughness in airdrying coatings for metal equipment. They contribute flexibility and adhesion to baking finishes—where their compatibility with other resins like ureas and melamines is essential.

Glycerine is also preferred in resin-making because of its better cooking qualities. With Glycerine, manufacture of alkyd resins is easily controlled to give a product of low acid number, without undue hazard of gelation.

If you'd like detailed information on the chemical and physical properties of Glycerine, write for your copy of "Why Glycerine for Alkyd Resins and Ester Gums?"

GLYCERINE PRODUCERS' ASSOCIATION

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CENTENNIAL EXCERPTS

(Continued from page 40)

The Dim Future

In all likelihood we shall see the operable high-pressure limits pushed upward by engineering and reflected first in research and then in manufacture of plastic materials. Is it not also possible that the available pressure range will be extended in the opposite direction also, as engineering provides economical means first for research and perhaps later for chemical manufacturing at lower and lower subatmospheric pressures? Engineering techniques for producing high temperatures and for effecting rapid cooling from those temperatures will be refined and followed by increasing utility in the plastics industry.

> Contributions of Engineering to the Plastics Industry Frank C. McGrew

2 As more and more of the fruit of nature's richness becomes plucked, more and more of the potentialities of empiricism, founded upon the structure of matter in bulk, become exhausted, and the more do we have to look to the subgrained atomic and nuclear structure of matter for further progress. The time is coming when the engineer will find that the sharpening of his old tools is not sufficient for his task. He must acquire new and strange tools, tools which seem antagonistic to his common sense. But common sense is a curious attribute. In its proper domain, it is a jewel of priceless value, but when strongly entrenched in any realm, it can impede progress. Fortunately, it is a changeable kind of thing. Like a chameleon, its colors alter with its surroundings, and it will happen in the future, as it has happened in the past, that the common sense of the past is the nonsense of today, and the new nonsense of today is the common sense of the future. It is for the young engineers to attune themselves to the common sense which is to come, that they may walk with the same security under its guidance as their predecessors have walked under the guidance of the common sense of their day.

> The Engineer and the Scientist W. F. G. Swann

The telephone engineer knows that his job will not be done until every man everywhere can speak to and see his fellow-man wherever he may be.

> The Telephone Engineer and His Job Hal S. Dumas

The Clear Past

Solvay's success was an engineering achievement of the highest order. He had to make a reversible reaction go by mass action effects. In order to do this he had to develop a type of lime kiln that would give high carbon dioxide concentration in the kiln gas. He had to design equipment for the decomposition of solid bicarbonate of soda under conditions that enabled him to recover the dioxide evolved at high yield and relatively undiluted with air. He had to build a pressure reactor for the operation and in this reactor he had to provide for effective countercurrent contact of the gas and liquid. Moreover, he developed this complicated combination of means for securing an adequate mass action effect six years before the law of mass action was discovered by the chemists Guldberg and Waage. In addition to all this, he had to have independent control of the temperature of the precipitating liquid and its residence time in the reaction zone. The ammonia he put through the process per cycle cost five times the value of his final finished product, so that he had to develop equipment in which mechanical losses of ammonia were negligible and a process which would recover ammonia in extremely high yield at low cost. These things he did represent superlatively good engineering. Moreover, Solvay was not alone in doing this sort of work; despite this fact, chemical engineering as a profession did not come into being in the nineteenth century. It is appropriate to mention that Solvay was a civil engineer.

Chemical Engineering—A New Science W. K. Lewis

2 There were times, before the advent of western railroad development and modern meat packing, that steers on the open range sold for as little as \$5 a head. Many of them were used just for their hides. A thousand miles away consumers wanted beef.

> Food Processing—A Century of Progress John Holmes

\$ The biggest single thing that has happened to agriculture in modern times has been the transition to power farming. . . .

In 1860, an Illinois farm paper reported what it called "the first actual success in steam plowing in America." The steam plow ran 23 minutes, stopped 6 minutes for wood, ran 13 minutes, stopped 8 minutes for water, ran 1 minute. It plowed 2.63 acres in 72 minutes, using 6 of a gang of 13 plows. The crew consisted of a man and a team of horses to supply fuel and water, a fire-

man, two men to manage the plows, and one of the inventors. In other words, five men and a team of horses to run one steam engine. The operation was a success, but the patient suffered a relapse when he saw the bill. . . .

From a total of 23,285,000 horses and mules in 1924, the number has decreased every year and was listed at 7,463,000 for 1950. Modern farm tractors gave the farm work horse a needed rest.

Farm Tractor Development and the Mechanization of Agriculture A. E. W. Johnson

He Has Worked

We must not forget that our entire country was originally agrarian. At the time of George Washington, about 98 per cent of our population was engaged in agriculture, and almost every year it was a task to keep the population from starving to death. Today only 12 per cent of our population is engaged in agriculture, and almost every year we over-produce every major crop.

Brief History of Engineering Education in the South Blake R. Van Leer

2 The huge growth of the inorganic chemical industry has not been due to a vast profusion of new chemicals, as in the case of the organic chemical industry, but rather to a vast expansion of facilities to produce the rather small list of chemical work horses such as ammonia, caustic soda, chlorine, hydrochlorie acid, nitric acid, phosphoric acid, salt cake, soda ash, and sulfuric acid.

Inorganic Chemical Technology—A Miracle
of Engineering
W. T. Nichols

It is largely true that there had been no really substantial advancement in farming methods and farming tools for thousands of years until about 100 years ago.

> The Machine Age of Farming Robert P. Messenger

The relief from some of the heavy burdens placed today upon the seeing organs, is becoming recognized as one of the greatest engineering contributions in recent years.

> Health and Human Engineering Samuel G. Hibben

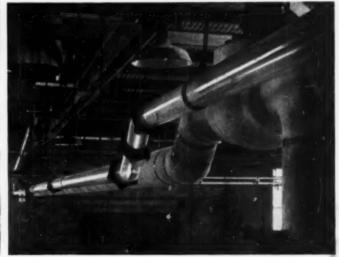
Philosophy

Progress can also mean improvement of such unglamorous factors as thermal efficiencies, yields, costs, and labor requirements.

> Century of Progress in Energy Eugene Ayres







What to consider

IN SELECTING CHEMICAL PLANT PIPING

IN specifying process pipe it is important to give proper weighting to replacement costs, maintenance, ease of cleaning and the visibility of a process. That's why it may pay you to review these facts about PYREX brand "Double-Tough" glass pipe:

Corrosion Resistance—Glass pipe provides corrosion resistance to an extremely wide range of chemicals. It withstands the effects of all acids, except hydrofluoric, and can be used with all but exceptionally strong caustics.

Visibility — Only glass permits you to actually see what is happening—helps you to keep a continuous check on your process.

Ease of Cleaning—The glass-smooth surface of PYREX pipe assures simple rapid cleaning by flushing. There are no truncations or grooves in which deposits can collect to foul the pipe or to contaminate sensitive solutions.

Rapid Assembly—PYREX pipe and fittings are designed for rapid installation even by inexperienced help. Field plumbing kits permit you to make odd lengths right on the job as shown at right above.



Cutting odd length is simple

Low First Cost—The initial cost of PYREX pipe is definitely in line with that of other chemical piping materials actually lower than most.

Low Replacement Costs — Not only corrosion resistance, but high resistance to both physical and thermal shock contribute to long service life. People respect glass, treat it carefully. Records prove that PYREX pipe is a genuine bargain. AMONG the biggest and most enthusiastic users of PYREX pipe today are those who tried a small installation "just to see how it would work." Why not you? There is a PYREX pipe distributor near you. He carries the complete line, including all fittings. Corning will gladly send you his name on request. Use the coupon below.

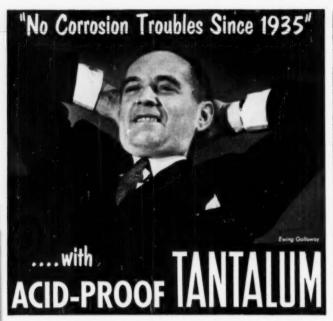
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Fansteel Metallurgical Corporation NORTH CHICAGO, ILLINOIS, W.S.A.

A.I.Ch.E. COUNSELING SESSION PLANNED

A counseling conference, the first of its kind in the history of the A.I.Ch.E., is scheduled as one of the features of the Cleveland meeting this December, according to Leon Chrzan, of the Institute's Professional Guidance Committee, under whose planning the conference was arranged.

Chrzan stated that the meeting was aimed at Junior members of the Institute who feel that an opportunity should be provided to discuss professional problems with older and more experienced men in the industry. Arrangements now call for small discussion groups to meet with senior and junior counselors who have had considerable industrial experience.

The program as outlined by the Professional Guidance Committee, will have Sidney D. Kirkpatrick, editorial director, McGraw-Hill Publishing Co., open the meeting with a talk entitled "At the Threshold of an Engineering Career." After the talk, the group will then separate into groups of eight, a question of importance will then be selected, and a pair of counselors will be chosen to discuss the question at the group's table.

"This conference," said Chrzan, "is a continuation of the Institute's early efforts in encouraging Junior members to explore the full depth of professional stature in the chemical field. The purpose of this conference is twofold: first it will provide the younger men with the opportunity to meet and talk with men who personify chemical engineering, and further will give them an opportunity to ask and discuss questions which are important in determining the correct course of their professional development."

"However the conference is not limited to Junior or Student members," he concluded, "and the Committee invites participation by all members of the A.I.Ch.E." It is expected the meeting will be held the evening of Monday, Dec. 8.

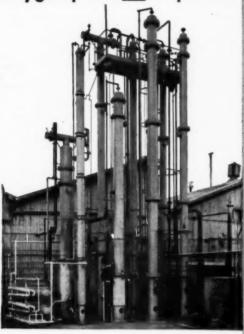
SECOND ANNUAL FACULTY LISTING

A new listing of chemical engineering faculty in the nation's colleges will soon be ready according to information received from the A.I.Ch.E. Chemical Engineering Education Projects Committee. The new listing will have more data than the first, according to Kenneth A. Kobe, professor of chemical engineering, at the University of Texas, and in charge of the project.

"This year," said Professor Kobe, "personnel departments of various companies have asked us to include more

(Continued on page 54)

Oxygen plant not required!



Wulff Process Recovery and Purification section. In operation over 19 months, the plant has sold acetylene commercially for the past 10 months.



This fully automatic cracking furnace is the heart of the Wulff Process. In the past 10 months of commercial operation, this unit has required no maintenance—capacities and yields have remained the same.

Available from Fluor

The Wulff Process for the production of acetylene from hydrocarbons is available through The Fluor Corporation. With over 30 years' experience in the design, engineering, and construction of plants and facilities for the petroleum and chemical industries, Fluor possesses the background, the skilled personnel, and the know-how essential for the practical application of the Wulff Process into your particular program.

THE WULFF PROCESS

Acetylene from natural gas, ethane, propane, butane, or any LPG mixture

available through Fluor!

The manufacture of acetylene from hydrocarbons by thermal pyrolysis is now commercially feasible and economically attractive! This has been proved. In January, 1951, the Wulff Process Company placed in experimental operation a commercial-sized acetylene plant. The plant has been operating continuously for the last 19 months. During the last 10 months of this period, acetylene has been sold commercially. This same process may be applied to plants making as little as one ton per day of acetylene to as much as one hundred tons or more per day.

The Wulff Process Company plant has experienced continuous operation on a wide variety of hydrocarbon feed stocks. Methane and propane have been used commercially. Test operations with ethane, butane and various hydrocarbon mixtures have demonstrated that a single plant with modification only in operating conditions can be used for a number of feed stocks. The process can be operated to produce substantial yields of commercial grade ethylene simultaneously.

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MARGINAL NOTES

News of Books of Interest to Chemical Engineers

A Vital Subject Brought Up to Date

Absorption and Extraction, Thomas K. Sherwood and Robert L. Pigford. McGraw-Hill Book Co., Inc., New York. (1952) 478 pp. \$7.50.

Reviewed by Bernard W. Gamson, Director of Res. and Dev., Great Lakes Carbon Corp., Morton Grove, Ill.

THE second edition of Absorption and Extraction is a joint revision of the first edition by Professor Sherwood, published in 1937. The fifteen years which have elapsed during the writing of these two volumes have been prolific with data and publications in the field of absorption and extraction. The current volume is an attempt to bring the literature of this period up to date for the chemical engineer.

There are ten chapters containing considerably new material over that of the first edition, and actually there is little recognition between the two volumes. Considerable emphasis has been placed in the first four chapters on both steady- and unsteady-state diffusion, eddy diffusion, and the theory of mass transfer from surfaces to fluid streams coupled with the attempt to develop the relationships between fluid friction, heat transfer and mass transfer by a single

Several excellent chapters are devoted to the design of absorption equipment as well as the design principles for multi-component systems. The latter subject does not cover the use of vaporization equilibrium constants and related activity coefficients for both the liquid and vapor states such as has been developed in recent years by several writers. This would be particularly desirable when dealing with light hydrocarbons where the normal vaporization equilibrium constants vary greatly with the solvent.

Two excellent chapters are devoted to the physical phenomenon associated with gas-absorption equipment and the performance of various types of vessels employed in carrying out absorption phenomenon. These cover data on packed towers, wetted-wall columns, spray towers, agitated vessels, and plate columns.

An excellent discussion is presented on simultaneous absorption and chemical reaction which summarizes the factors effecting chemical reaction and adsorption rate. A marked theoretical advance over the past literature has been developed and is presented by the authors.

The section on solvent extraction is covered by one chapter and could be expanded upon to make the discussion more comprehensive.

This volume is definitely recommended for every chemical engineer, both in the university and in practice. In fact, it is a must in the reviewer's opinion for those engaged in the field of absorption and extraction. It is a worth-while addition to the literature of chemical engineering.

A "Bon" from Mott

Practical Radiography for Industry. H. R. Clauser. Reinhold Publishing Corp., New York. (1952) 301 pp. \$7.50.

Reviewed by N. S. Mott, Chief Chemist & Metallurgist, The Cooper Alloy Foundry Co., Hillside, N. J.

In the opinion of this reviewer, this book is one of the finest practical manuals on the subject of radiography to date, and although the price seems to be a little on the high side for a volume of its size, the extensive coverage and understandable clearness of the text make it well worth the expenditure for anyone concerned with the nondestructive testing of materials.

Concise information aided by nearly 200 illustrations is found on all radiographic subjects including a theoretical discussion, equipment types, applications, operating techniques, interpretations and standards. The separate chapters devoted to radium and cobalt 60 radiography, betatran radiography, fluoroscopy, and miscellaneous applications such as radiation detectors, microradiography, and thickness-gaging methods, round out the general coverage of the subject of industrial radiography.

The relatively nontechnical manner of explanation makes the book valuable for the training of students or assistant radiographic technicians; however, it could also be a valuable addition to the reference bookshelf of any engineer, metallurgist, inspector, or even an experienced radiographer.

Books Received

Acids and Bases. Their Quantitative Behaviour. R. P. Bell. Methuen's Monographs on Chemical Subjects. John Wiley & Sons, Inc., New York. (1952) 90 pp. \$1.50.

Advanced Statistical Methods in Biometric Research. C. Radhakrishna Rao. John Wiley & Sons, Inc., New York. (1952) 390 pp. \$7.50.



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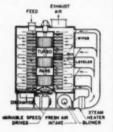


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FACULTY LISTING

(Continued from page 50)

information. In addition to a listing of the names and positions of all teaching personnel in every chemical engineering department in the country, we will have information of the degrees granted at each college, type of graduate work, accrediting information, and the number of unfilled staff positions."

The listing was first published by the Projects Committee in 1951, and will be free to members of the American Institute of Chemical Engineers.

It is expected that this list will be available about Nov. 15, 1952.

Please address the Secretary at 120 East 41st Street, New York 17, N. Y.

HUMBLE LECTURE SERIES ANNOUNCED

The seventh annual series of Lectures in Science at Humble Oil and Refining Co.'s Baytown refinery will be presented by five professors from schools well scattered geographically. Dr. Henry Eyring, professor and dean of the Graduate School. University of Utah, will lead off in November with a course on Kinetics and Catalysis. He will be followed by Dr. Joseph O. Hirschielder, professor and director of the Naval Research Laboratory. University of Wisconsin, in January, on Transport Properties of Fluids. In March, 1953, Dr. Frederick G. Bordwell, assistant professor of chemistry, Northwestern University, will conduct a course on Chemistry of Organic Sulfur and Nitrogen Compounds. Dr. Joseph C. Elgin, professor and associate dean of the School of Engineering, Princeton University, will lecture on Solvent Extraction, the first of April. Dr. Richard G. Folsom. chairman, division of mechanical engineering, University of California, will present a course in Fluid Mechanics, in lune.

Each of the courses extends over approximately two weeks, and is a fulltime assignment for the members of Humble's technical staff who participate.

COURSES IN RADIO-ISOTOPES TECHNIQUES

Basic courses in radioisotope techniques in research will be offered by the Oak Ridge Institute of Nuclear Studies on January 5, February 2, and March

Application blanks and other information on the one-month courses may be obtained from Ralph T. Overman, Chairman, Special Training Division, Oak Ridge Institute of Nuclear Studies, P. O. Box 117, Oak Ridge, Tenn.

(More News on page 62)

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CANDIDATES FOR MEMBERSHIP IN A. I. Ch. E.

The following is a list of candidates for the designated grades of membership in A.I.Ch.E. recommended for election by the Committee on Admissions.

These names are listed in accordance with Article III, Section 7, of the Constitution of A.I.Ch.E.

APPLICANTS FOR
ACTIVE
MEMBERSHIP

Barry, Charles B., Tulsa, Okla.

Bohlig, Edward L., Hopewell, Va.

Brensilber, Efream I., Brooklyn, N. Y. Brown, David, Emeryville,

Calif.
Bulls, James W., Terre

Haute, Ind. Burk, Chapman, El Cerrito,

Carbone, Walter E., Madison, N. J.

Casten, James W., Buffalo,

Cavataio, Jerald A., North Arlington, N. J.

Charity, Neil M., Lawrenceburg, Ind. Chenevey, John E., Roselle Park, N. J.

Coli, G. J., Jr., Hopewell, Va.

Collinge, H. K., Montreal, Que., Canada

Danehower, Robert G., Phila., Pa.

Deaderick, James W., Signal Mountain, Tenn. Dean, C. W., Memphis,

Tenn. DiPace, Joseph A., Paris,

Dorris, Thos. B., Oakland, Calif.

Flamm, Paul F., Kingsport, Tenn.

Fontaine, Francis E., Pearl River, N. Y.

Ghublikian, John R., Boston, Mass.

Hankey, E. H., Springfield, Mass. Objections to the election of any of these candidates from Active Members will receive careful consideration if received before November 15, 1952, at the Office of the Secretary, American Institute of Chemical Engineers, 120 East 41st., New York 17, N. Y.

Henzmann, Robert E., Charleston, W. Va.

Hilinski, Francis A., Louisville, Ky.

Jackson, Robert M., Rochester, N. Y.

Junker, Thomas J., Pittsburgh, Pa.

Karr, Andrew E., Bloomfield, N. J. Keane, John D., Oak Park,

Ill.

Keene, Wilson B., Forest

Hill, Md. Koch, W. C., Marcus Hook, Pa.

Lane, William Hugh, Texas City, Tex.

Lang, Edward W., Birmingham, Ala.

Luckring, R. M., Wilmington, Del.

Mason, Donald R., Morristown, N. J. May, Walter G., Union, N. J.

N. J. McIntosh, J. L., Metuchen,

Minet, Ronald G., Phila., Pa.

Oldaker, Jay F., Charleston, W. Va. Palm, J. W., Tulsa,

Okla. Reinker, Robert E., Midland, Mich.

Rosebrock, Frederick H., Jr., Rockville Centre, N. Y.

Saner, H. Albert, Bozeman, Mont. Seglin, Leonard, White

Plains, N. Y.
Seubert, Robert F., Oil City,
Pa.

Shuffle, Edwin, Jr., Charleston, W. Va. Simon, Robert H., Scotia, N. Y.

N. Y. Smith, Frederick W., Allen Park, Mich. Smith, Loyd T., Pawhuska,

Ohla. Smith, Thomas J., Jr., Stamford, Conn.

Stevens, James E., Jr., Nashville, Tenn. Stras, James C., Jr., Kinga-

port, Tenn. Stueber, Curtis C., Akron, Ohio

Taylor, James A., Romulus, Mich. Thompson, Howard F.,

Chester, Pa.
Weinstein, Seymour,
Chicago, Ill.

Weyrich, John C., Louisville, Ky. White, D. H., Bartlesville, Okla.

Wilson, Virden W., Houston, Tex.

> APPLICANTS FOR ASSOCIATE MEMBERSHIP

Hendrickson, John R., Bel Air, Md. Luzader, G. Brooks, South Charleston, W. Va. Montgomery, Robert N., Houston, Tex.

Shaw, Wesley Samuel, Pittsburgh, Pa.

> APPLICANTS FOR JUNIOR MEMBERSHIP

Adams, R. O., Wilmington, Del. Anderson, Douglas W.,

Berkley, Mich.
Armstrong, Phillip E.,
Charleston, W. Va.
Atwood, James D., Edin-

burg, Tex.
Babb, A. L., Seattle,
Wash.

Bach, Robert J., Jr., Milwaukee, Wis. Ballmer, Charles L., Norwalk, California

Bearden, John T., Louisville, Ky.

Berry, William H., Jr., Louisville, Ky. Burns, John C., Jr.,

Houston, Tex.
Caccavo, Frank V.,
Brooklyn, N. Y.
Cairne Stanley W. No.

Cairns, Stanley W., New Rochelle, N. Y. Daley, Allen M., Lewiston, N. Y.

Dalrymple, Robert Roy, Passaic, N. J.

DaVanzo, Albert Arthur, Army Chemical Center, Md.

Davis, Kenneth W., Houston, Tex.

DeGraff, Richard R., San Francisco, Calif. DeLisle, Norman G.,

Midland, Mich.
Desai, Krishna, Brooklyn,
N. Y.

Destremps, Edward A., Brooklyn, N. Y. Dvorsky, Edward, Jr., Niagara Falls, N. Y.

(Continued on page 58)

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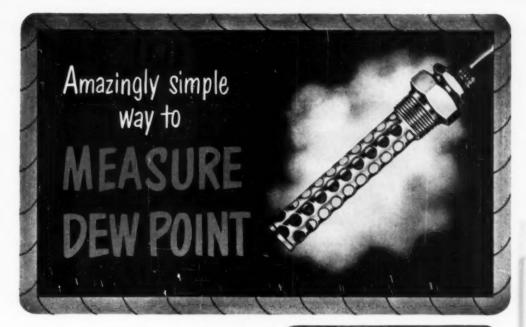
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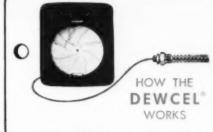
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CANDIDATES

(Continued from page 56)

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Feinman, Jerome, Brooklyn, N. Y.
Fisher, Robert A., Oak Ridge, Tenn.
Gleason, Gerald H., New Rochelle, N. Y.
Graves, John T., Westport, Conn.
Greenwood, Billy S., Baytoun, Tex.
Guon, Jerold, Chicago, Ill.
Gussow, Stanley, Newark, N. J.
Hansen, Richard L., Minneapolis,
Minn.
Harkreader, Gordon G., Greenwood,
Ark.

Harris, John M., Wilmington, Del. Hartsoe, Joseph D., Falls Church,

Va.
Heil, C. Richard, Springfield, Ohio
Hoppe, Ray Alden, Charleston, W. Va.
Johnson, Ronald L., Midland, Mich.
Kardash, Walter A., New York, N. Y.
Kasbohm, Martin, Grand Island,

Kjellmark, Eric W., Jr., Scarsdale, N. Y.

Lance, Ronald Price, Springfield, Mass.

Mass.
Larkin, David E., Savannah, Ga.
Lee, Donald H., Teaneck, N. J.
Lewis, E. Wayne, Baytown, Tex.
Lobo, Paul A., Westfield, N. J.
Magin, Kenneth E., Barrington, N. J.
McCurdie, Don C., Pocatello, Idaho
McGarry, William T., Rochester, N. Y.
McGlynn, Edward S., Chicago, Ill.
McLain, William G., Louisville, Ky.
Menzemer, Charles LeRoy, Army

Chemical Center, Md.
Mohr, Lawrence C., Chicago, Ill.
Moser, Richard J., Kalamazoo, Mich.
Myers, Richard E., Grand Island,
N. Y.

Nickolaus, Nicholas, Forest Hills, N. Y.

Oliphant, Edgar, Jr., Richmond, Mo. O'Reilly, Michael, Flushing, N. Y. Ozkardes, Haldun, New York, N. Y. Parker, Norman H., Woodside, N. Y. Person, Rolph A., Milwaukee, Wis. Phillips, Russell C., Menle Park, Calif. Pollock, Duane Rex, Seattle, Wash. Pope, Robert E., Lauvence, Kan. Rachford, Henry H., Jr., Houston, Tex.

Reynolds, Jack B., Houghton, Mich. Samuels, Julian J., Goodwater, Ala. Schaffstall, Eugene, Buffalo, N. Y. Scriven, L. Edward II, San Mateo, Calif. Seid, Paul E., Mount Vernon, N. Y. Sheppard, Robert B., Webster Groves,

Shinners, Edward M., Niagara Falls, N. Y.

Simonson, Frank L., Lakewood, Ohio Siragusa, Gregory J., Newport News, Va.

Slavin, James, Detroit, Mich.
Sourelis, Stanley G., Chicago, Ill.
Staubs, Harry Leo, Martinaburg, W. Va.
Stine. Roy L., Vernon, Tex.
Struch, Walter E. A., Boston, Mass.
Sudak, Richard G., Richland, Wash.
Swandby, Richard K., Minneapolis,

Minn. Tatom, Keith K., Jr., Santa Barbara, Calif.

Catt.
Thiele, R. E., Jr., Coleman, Mich.
Van Arnum, Wm. H., Westfield, N. J.
Waide, Charles H., Upton, N. Y.
Weisemann, Gert H., Whiting, Ind.
Werner, Harold V., Newport, Del,
Yemc, Bernard A., Grand Haven,
Mich.

Secretary's Report

S. L. TYLER

THE September meeting of the Executive Committee was held at the Palmer House, Chicago, Ill., Sept. 11. The Minutes of previous meetings, Treasurer's report for the month of August, and bills for the month of August were received and approved. No adverse comments having been received regarding those applicants for membership whose names appeared in the August issue of C.E.P., the candidates were elected to the grades of membership as indicated. Seven applicants were elected to the grade of Student membership.

Henry H. Hubble, Jr., was appointed to the Membership Committee to replace E. B. Gunyou of the Columbia Valley Section. Robert F. Romell was appointed to the Research Committee.

The Public Relations Committee had submitted a draft of a questionnaire to be sent to the membership of the Institute in order to obtain statistical information on the membership of the Institute and also opinions on general Institute policies. This questionnaire was studied at considerable length and a few modifications made which were to be recommended to the Council for its approval.

The Council of the Institute met at the Palmer House in Chicago, on the afternoon of Sept. 13. Minutes of previous meetings of both the Executive Committee and Council were approved.

O. A. Hougen, chairman of the Awards Committee, presented an interim report covering the activities of the committee for the year.

Mott Souders, chairman, of the Symbols and Nomenclature Committee, also presented an interim report of the activities of his committee. He reported that the committee is now working on a set of symbols for use on drawings.

The questionnaire submitted by the Public Relations Committee was presented to Council and the recommendations of the Executive Committee were considered. The questionnaire was approved for submission to the membership with the final draft subject to the approval of the Executive Committee. This questionnaire will be sent to all members of the Institute and their cooperation is earnestly requested in order that the results may be accurate.

The President reported the appointment of the Tellers Committee to count and report on the Nominating and Election Ballots for officers for 1953 and Directors for 1953-1955: E. F. Jennings, Jr., chairman: O. C. Karkalits, T. H. Kelly, and S. M. Sheerin, secretary.

(Continued on page 67)

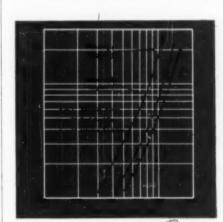


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LETTERS TO THE EDITOR

ELECTIONEERING SCORED

At a recent meeting of the Executive Committee of the New Jersey Section, there was some discussion of the increasing number of leaflets and letters received from other sections designed to secure support for their candidates for Directors of the Institute. We feel that this is an undesirable trend and that some action, formal or informal, should be taken to stop it before it reaches the proportions of an active electioneering campaign.

It undoubtedly arose as an attempt by the sponsoring section to bring the qualifications of little-known men to national attention, but it will almost certainly deteriorate to the point where each section feels compelled to follow suit. Perhaps in the future each section might be asked to submit a short biography of its suggested nominee for publication in "C.E.P." or perhaps these biographies could be circulated with the ballots. In any case, we feel that something should be done to keep active electioneering from becoming the accepted thing. Certainly no one wants to see it pursued to the ultimate which might easily result in coalitions of Sections such as New York. New Jersey. and Philadelphia - Wilmington, which could undoubtedly elect two or three Directors every year.

If it is felt necessary to obtain the election of Directors from various parts of the country, some form of regional directorships might be set up to ensure this. It is questionable, however, that there are actually any regional interests which require advocacy on the Council.

T. H. Kelly

New York, Sept. 8, 1952

ARE YOU CIVIC-MINDED?

Sir:

I was very much interested in Mr. R. H. Price's "Civic Responsibilities of the Engineer" in the July Chemical Engineering Progress, having served as an elected member of the town board of a suburban city of 4,000 and as Chairman of its Public Safety Committee (Police and Fire Department). I personally know of at least half a dozen other chemists and engineers who have served in similar capacities. I feel qualified to affirm Mr. Price's contention that engineers should take a place in firstlevel government.

It is a fact that, by training, engineers are more capable of introspective examination of the facts whereas the extroverted people, one finds so universally in public office, are less well equipped for this extremely vital function.

One hears much talk of the "profession" of engineering. A hallmark of a "professional man" in law, medicine, or the clergy is his interest in his community. The engineer cannot escape his obligation as an ordinary citizen by claiming, in humility, that he is no better fitted for local government than his neighbor.

As Mr. Price suggests, participation in community affairs is not only a professional responsibility, but a personal opportunity.

H. E. Wessel

Kansas City, Mo., July 31, 1952.

NEWS

(Continued from page 54)

MASS-TRANSFER SCHOOL OF A.I.Ch.E. AND SHELL

The Shell Development Co., Emeryville, Calif., conducted the first school in the Far West on Sept. 15 for teachers of chemical and process engineering. The day's program was on mass-transfer fundamentals and operations, which was participated in by people from Washington, Stanford, U.C.L.A. and California (Berkeley).

Continuing the work of the Chemical Engineering Education Projects Comnittee of A.I.Ch.E., the initial arrangements for the school were made with Shell Development by Paul B. Stewart of the Process Group at the University of California for the Committee.

After a short introductory talk by Mott Souders, Jr., the morning program was devoted to discussions of fundamental problems in extraction by Thomas Baron, mechanics of drops and bubbles by Richard R. Hughes, and fundamentals of vapor-liquid contacting by Richard B. Olney. Shell movies illustrated the operation of the equipment being discussed. Luncheon was followed by an inspection, discussion, and explanation of certain Shell equipment, after which the group broke up into small discussion groups.

Those attending were: A. L. Babb, University of Washington; C. B. Lindquist and R. R. Paxton, Stanford University; N. K. Hiester, Stanford Research Institute and Stanford University: T. J. Connolly and John C. Harper, U.C.L.A.; C. R. Wilke, K. F. Gordon and C. W. Tobias, University of California (Berkeley) chemical engineering division; and R. G. Folsom, R. V. Dunkle, L. Farbar, H. W. Iversen, H. A. Johnson, F. Kreith, N. W. Snyder, P. B. Stewart, C. J. Vogt, and A. K. Oppenheim, University of California (Berkeley), process and mechanical engineering.



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NEWS

(Continued from page 61)

ISOTOPE CONTROLS CARBON DEPOSITION

A beta ray source and detector are now being used to control the amount of carbon applied on carbon paper in the plant of the Standard Register Co., Dayton, Ohio. The device was installed, company officials said, to solve the problem of maintaining absolute quality of the miles of carbon paper produced annually.



A carbon department supervisor points out features of the operation.

Basically the beta gauge manufactured by the Industrial Nucleonics Corp. works as follows: On an arm located beneath the paper being carbon-coated, is a source box containing a capsule of Strontium-90. The Strontium, a by-product of the nuclear piles at Oak Ridge, constantly emits a stream of beta electrons upward through the material. On the gauge arm extending above the paper is a detector which picks up the beta electrons that penetrate the paper.

The more carbon that is added, the fewer electrons penetrate the sheet. These variations in thickness are transmitted to a recorder chart and enable the operator to see at a glance how much carbon is being applied at the moment the tissue comes out of the coater. This recording chart is calibrated to read in pounds of coating per ream.

The amount of coating, therefore, can be held to specifications. The detector unit moves back and forth across the web during the operation of the machine and measurements can be taken across the web of paper.

Present plans are being made to use the device as a sensing element in an automatic control system that will mechanically make adjustments to the

TO DEDICATE CHEM. ENG. WING AT DELAWARE UNIV.

Plans have been completed for a oneday program, Oct. 18, 1952, marking the formal dedication of the chemical engineering addition to H. Fletcher Brown Laboratory at the University of Delaware, Newark.

The dedication ceremonies will begin at 10:00 A.M. in Mitchell Hall. Following a welcome by Dr. John A. Perkins, president of the university. a history of chemical engineering at Delaware will be given by Dr. R. L. Pigford, chairman of the chemical engineering department.

A feature of the morning program will be greetings from the president of the American Institute of Chemical Engineers, William I. Burt, from W. E. Chalfant, the chairman of the Philadelphia-Wilmington Section of the American Institute of Chemical Engineers, and others.

The morning session will be highlighted by the presentation of Certificates of Professional Achievement to University of Delaware alumni in chemical engineering and chemistry who have contributed to the country's professional progress.

The afternoon scientific conference devoted to the subject of chemical reaction kinetics will be held at 1:30 P.M. in the H. Fletcher Brown Laboratory auditorium. Dr. Farrington Daniels, professor of physical chemistry and chairman of the department of chemistry, University of Wisconsin, and president-elect, American Chemical Society, will speak on "Kinetics of Nitrogen Oxides." Dr. Richard H. Wilhelm, professor of chemical engineering, Princeton University, will discuss "Mechanisms of Mixing in Fixed and Fluidized Beds." These addresses will be followed by discussion of research-inprogress at research sites by the staffs of chemical engineering and chemistry, and a tour of the laboratory.

PLASTICS RESEARCH ON BALLOONS AT IOWA STATE

The Aeronautical Research Laboratory of General Mills, Inc., is currently sponsoring at the State University of Iowa a college of engineering research project on the development of plastic materials for the construction of high-altitude balloons. The work at the university is being carried on by three university students of the chemical engineering division under the direct supervision of Karl Kammermeyer, professor of chemical engineering and the cooperation of J. O. Osburn, of the chemical engineering staff.



The above photo of acid storage tanks clearly illustrates the difference between good and poor paint maintenance programs. Taken at Pennsalt's Wyandotte, Mich., plant, it shows part of the results of a 3-year study of painting programs. The method was developed by actual painting crews and plant engineers

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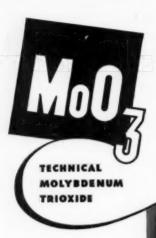
Of course, the subject is too complex to be discussed in detail here. But a word from you will bring complete data to you on the run. Write: Corrosion Engineering Products Department, Pennsylvania Salt Manufacturing Co., Philadelphia 7, Pa.





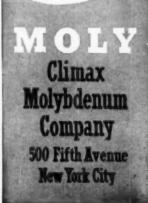






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FUTURE MEETINGS AND SYMPOSIA OF A.I.Ch.E.

Chairman of the A.I.Ch.E. Program Committee

Walter E. Lobo, The M. W. Kellogg Co., 225 Broadway, New York 7, N. Y.

MEETINGS

Annual — Cleveland, Ohio, Hotel Cleveland and Carter Hotel, Dec. 7-10, 1952.

Technical Program Chairman: R. L. Savage, Dept. of Chem. Eng., Case Inst. of Tech., Cleveland 6, Ohio.

Biloxi, Miss., Buena Vista Hotel, Mar. 8-11, 1953.

Tochnical Program Chairman: Norman A. Spector, Vitro Corp., 233 Broadway, New York 7, N. Y.

Toronto, Canada, Royal-York Hotel, April 26-29, 1953.

Technical Program Chairman: Brymer Williams, Dept. of Chem. and Met. Eng., University of Michigan, Ann Arbor, Mich.

San Francisco, Calif., Fairmont and Mark Hopkins Hotels, Sept. 13-16, 1953.

Technical Program Chairman: R. W. Moulton, Head, Dept. of Chem. Eng., University of Washington, Seattle, Wash.

Annual-St. Louis, Mo., Hotel Jefferson, Dec. 13-16, 1953.

Technical Program Chairman: R. M. Lawrence, Monsanto Chem. Co., St. Louis 4, Mo.

SYMPOSIA

Applied Thermodynamics

Chairman: W. C. Edmister, California Research Corp., Richmond, Calif.

Meeting-Cleveland, Ohio

Human Relations

Chairman: R. L. Demmerle, General Aniline & Film Corp., 230 Park Ave., New York, N. Y. Meeting—Cleveland, Ohio.

Modern Statistical Methods in Chemical Engineering

Chairman: C. Daniel, Engineering Statistician, 116 Pinehurst Ave., New York 33, N. Y. Meeting—Cleveland, Ohio.

Filtration

Chairman: F. M. Tiller, Dir., Div. of Eng., Lamar State College of Technology, Beaumont, Tex.

Meeting—Cleveland, Ohio

High Pressure

Chairman: E. W. Comings, Head, School of Chem. & Met. Eng., Purdue University, Lafayette, Ind. Meeting—Cleveland, Ohio.

Mineral Engineering Techniques for Chemical Engineers

Chairman: N. Morash, Titanium Div., National Lead Co., P. O. Box 58, South Amboy, N. J.

Co-Chairmen: T. S. Leary, Calco Chem. Div., Bound Brook, N. J., and D. W. Oakley, Metal & Thermit Corp., Carteret, N. J. Meeting—Biloxi, Miss.

Ion Exchange

Chairman: N. R. Amundson, Dept. of Chem. Eng., Univ. of Minnesota, Minneapolis 14, Minn.

Meeting—San Francisco, Calif.

Mixing

Chairman: J. H. Rushton, Dept. of Chem. Eng., Illinois Inst. of Tech., Chicago, Ill. Meeting—San Francisco, Calif.

Dust and Mist Collection

Chairman: C. E. Lapple, Dept. of Chem. Eng., Ohio State University, Columbus 10, Ohio.

Chemical Engineering in Hydrometallurgy

Choirman: John D. Sullivan, Battelle Memorial Institute, Columbus, Ohio.

Co-Chairman: John Clegg, Battelle Memorial Institute, Columbus, Ohio.

Fluid Mechanics

Chairman: R. W. Moulton, Head, Dept. of Chem. Eng., University of Washington, Seattle, Wash.

Absorption

Chairman: R. L. Pigford, Div. of Chem. Eng., Univ. of Delaware, Newark, Del.

Authors wishing to present papers at a scheduled meeting of the A.I.Ch.E. abould first query the Chairman of the A.I.Ch.E. Program Committee. Walter E. Lobo, with a carbon copy of the letter to the Technical Program Chairman of the meeting at which the author wishes to present the paper. Another carbon should go to the Editor, F. J. Van Antwerpen, 120 East 41st Street, New York 17, N. T. If the paper is suitable for a symposium, a carbon of the letter should go to the Chairman of the Symposia, instead of the Chairman of the Technical Program, since symposia are not scheduled for any meeting until they are complete and approved by the national Program. Committee, Before authors begin their manuscripts they should obtain from the meeting Chairman a copy of the Guide to Speakers. The first book covers the preparation of manuscripts, and the second covers the proper presentation of papers at A.I.Ch.E. meetings. Presentations of papers are judged at every meeting and an award is made to the sensker who delivers his paper in the best manner. Winners are annuanced in Chemical Springering of this local section. Since the copies of the manuscript of the Technical Program Chairman of the meeting, or two the copies of the manuscript to the Technical Program Chairman of the meeting, or two the Technical Program Chairman of the meeting, or two the Technical Program Chairman of the meeting, or two the Technical Program Chairman of the meeting, or two the Technical Program Chairman of the meeting of this local section.

CALENDAR OF MEETINGS

Below is a partial list of scheduled meeting dates of local sections. All Institute members when in the vicinity are cordially invited to attend. Supplemental Lists will be published as fast as the information is received in the Secretary's office.

Baton Rouge. No definite schedule avail-

Contact: R. W. Krebs, 1272 Alfred St., Baton Rouge, La. J. M. Gill, 4434 Arrow-head St., Baton Rouge.

Central Virginia. Nov. 14. No meetings will be held during the months of December, January or February.

Contact: O. L. Updike, University of Virginia, Charlottesville, Va. G. C. Gross, Du Pont Co., Waynesboro, Va. S. O'Donnell, Merck and Co., Elkton, Va. C. W. Sieber, Calco Chemical Div., American Cyanamid Co., Piney River (Nelson County). Va. County), Va.

Columbia Valley (Richland, Wash). Oct. 24, Nov. 20, 1952.

Contact: H. E. Hanthorn, 1107 Perkins Ave., Richland, Wash. Phones: Office, 8-3301; home, 4-7707. E. R. Irish, 1103 Williams, Richland. Phones: Office, A-7431; home, 7-9783.

Kansas City. Nov. 29.

Contact: H. H. Young, Midwest Research Institute, 4049 Pennsylvania, Kansas City, Mo. Phone: LO. 0203. Ben Olson, Standard Oil Co., Sugar Creek, Mo. Phone: CL. 4800.

New York. Oct. 21, Nov. 19, Dec. 16, Jan. 21, 1953, Feb. 17, March 19, April 22, May 19 and June 18.

Contact: F. B. White, Foster Wheeler Corp., 165 Broadway, New York 6, N. Y.

Ohio Valley (Cincinnati, Ohio). Nov. 3, Dec. 1, Jan. 21, 1953, Feb. 2, March 6, April 24, May 4, and June 1.

Contact: A. C. Greber, T. B. Wiehe, A. B. Davidson, Schenley, Distillers, Inc., 26 East 6th St., Cincinnati 2, Ohio. Phone:

Philadelphia - Wilmington. Oct. 21, Nov. 13, Nov. 18, Jan. 13, 1953, Jan. 20, Feb. 10, Feb. 17, March 10, March 17 and April 14.

Contact: W. E. Chalfant, The Atlantic Refining Co., Philadelphia, Pa. Phone: Howard 5-2345. R. A. Kinckiner, Du Pont Co., Wilmington, Del. Phone: Wilmington 4-5121. N. H. Walton, The Atlantic Refining Co., Philadelphia. Phone: Howard 5-2345.

Rochester. Nov. 19, Jan. 21, 1953, Feb. 18, March 18, April 15 and May 20. Contact: Irving Siller, Pfaudler Co., Rochester, N. Y. Phone: Genesee 8120.

St. Louis. Oct. 21, Nov. 18, Dec. 16, Jan. 20, 1953, Feb. 17, March 17, April 21 and May 19.

Contact: C. P. Orr, Monsanto Chemical Co., 1700 South Second St., St. Louis 4, Mo. D. E. Morris, Organic Div., Malline-krodt Chemical Works, 3600 North Second St., St. Louis 7, D. F. Chamberlain, chem. eng. dept., Washington University, St. Louis 5.

(Continued on page 66)

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CALENDAR OF MEETINGS

(Continued from page 65)

South Texas (Houston). Oct. 24, and the third Friday of the succeeding months.

Contact: W. B. Franklin, Humble Oil & Refining Co., Baytown, Tex. C. L. Dickinson, Kolker Chemical Works, Inc., P.O. Box 9637. Houston 15, Tex.

Twin City (Minneapolis - St. Paul). Meetings are held on the third Wednesday of every month, alternating between Minneapolis and St. Paul.

Contact: R. H. Fredrickson, Minneapolis Mining & Mfg. Co., 900 Fauquier Ave., St. Paul 6, Minn.

NORTHEASTERN NEW YORK CHEMICAL ENGINEERS

The first meeting of the club was held in Schenectady, N. Y., Sept. 9, Thirty-one persons present heard a talk by C. F. Palmer, of the Behr-Manning Corp., on the topic "A Two-Bit Tour of the U. S. Patent Law." Mr. Palmer, a patent attorney, has spent the past ten years in patent practice.

A committee has been formed to schedule and to provide men from industry for talks to the Rensselaer Polytechnic Institute chemical engineering seniors as a part of the spring 1953 curricula.

Reported by R. E. Larson

SOUTHERN CALIFORNIA

The August meeting was held at the Midland Rubber Corp. plant with 123 members and guests present. The speaker for the evening, John Whaley, technical superintendent of the Midland Rubber Corp., discussed briefly the process for the manufacture of GR-S synthetic rubber and outlined the problems which were encountered in developing the cold rubber process. In addition he described the new processes of manufacturing oil-extended rubbers and carbon black master batch. Following the discussions, the members were conducted through the plant.

At the next meeting, "What A Research Institute Means to the West" will be discussed by F. S. Sawyer, assistant to the director of research at Stanford Research Institute.

Reported by Gale S. Peterson

ST. LOUIS

The first meeting of the season was held Sept. 16, 1952, at the Anheuser-Busch brewery in St. Louis. Seventythree members and guests were present.

Reported by R. G. Kerlin

ATLANTA

The first meeting of this Section since its authorization as a local section was held Sept. 11. Forty members and guests heard Roy W. Sudhoff, associate director of development for the newly organized Chemistrand Corp., speak on the uses and preparation of synthetic fibers.

Reported by Robert C. Barrett.

NEW YORK

L. C. Kemp will give an address Nov. 19, 1952, at 6 P.M., at the Brass Rail, 521 Fifth Avenue. His subject is Economics of Coal Hydrogenation for Synthetic Fuel.

Mr. Kemp is director of research, technical and research division, The Texas Co., New York.

Reported by Richard F. Shaffer

SECRETARY'S REPORT

(Continued from page 59)

The chairman of the Local Sections Committee recommended the approval of the application for a local section to be known as the Northeastern New York Section with headquarters at Schenectady, N. Y.; his recommendation was received and approved.

The next meeting of the Council will be held Nov. 14 at The Chemists' Club, New York City.

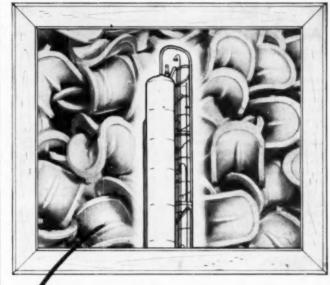
SINCLAIR SPONSORS NEW FELLOWSHIPS

Sinclair Refining Company has established seven new fellowships for students working for their master's or doctor's degrees, P. C. Spencer, President, announced recently.

The new fellowships, which become effective in September at the Universities of Michigan, Nebraska, Wisconsin, Wyoming, Illinois Institute of Technology, Pennsylvania State College, and Washington University (St. Louis), are in addition to six previously established at the Universities of Chicago, Illinois, Notre Dame, Oklahoma, Colorado School of Mines and Northwestern University. All of the previously established fellowships, the first of which was inaugurated in 1946, are being renewed for 1952-53.

Each fellowship is in the amount of \$2500 of which \$1500 will be stipend for the student and \$1000 for tuition, laboratory fees, etc.

With the seven new awards, Sinclair Refining Company now sponsors two fellowships in geology, two in geophysics, four in organic chemistry, two in petroleum production engineering, one in chemical engineering, one in physical chemistry and one in catalytic research.





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PEOPLE

Kenneth M. Watson has recently joined The Pure Oil Co., Chicago, Ill.,



as director of research. Prior to this association Dr. Watson operated a consulting service for the past two years. Now he will be located in the company's research and development laboratories in Crystal Lake, III.

After receiving his B.S. and M.S. degrees at Wisconsin, he joined the Hawthorne Works of Western Electric Co. as an assistant in engineering development. In 1926 he returned to the chemical engineering staff at the University of Wisconsin where he received his doctorate in chemical engineering in 1929. Two years later he joined the staff of the Riverside laboratories of Universal Oil Products, and later was appointed director of engineering research. From 1942 to 1950 Dr. Watson was research professor of chemical engineering in the Graduate School of the University of Wisconsin. He was also a consultant to the War Production Board, Office of Rubber Reserve, and was technical adviser to the President's interagency committee in 1945.

Dr. Watson, in 1948, received the William H. Walker Award of A.I.Ch.E.,

C. C. Furnas, director of the Cornell Aeronautical Laboratory, Inc., Buffalo, N. Y., was recently appointed chairman of the Guided Missiles Committee for the Research and Development Board, Department of Defense.

Karl Kammermeyer spent the summer as a consultant with the Sandia

Corp., Sandia Base, Albuquerque, N. M., where he worked in the weapons effect department. Dr. Kammermeyer is head of the division of chemical engineering and professor of chemical engineering at the State



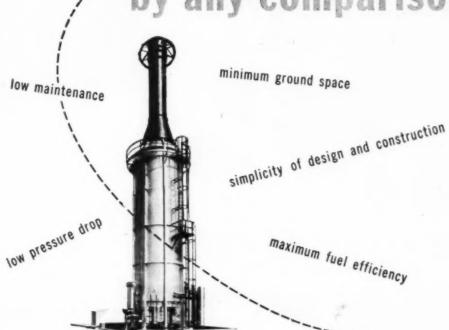
University of Iowa. He has been associated with the Standard Oil Company of Indiana; Pure Oil Co.; the Drexel Institute, as teacher of chemical engineering, and with the Publicker Industries. He received his early education abroad and took a D.Sc. degree in chemical engineering from the University of Michigan.

(More About People on page 70)

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PEOPLE

(Continued from page 68)

F. Drake Parker has been appointed manager of the reorganized Tulsa.



Okla., office of the chemical plants division of Blaw-Knox Co. It will be a complete operating unit to be known as the Western headquarters. A chemical engineering graduate of the University of Michigan, Mr. Parker

goes to Blaw-Knox from the Badger process division of Stone & Webster Engineering Corp. where he has been chief process engineer. Earlier in his career, Mr. Parker served as Western representative of the Houdry Process Corp.; chief process engineer of the Bechtel Corp.; and research supervisor of the Union Oil Co. of California.

The Western headquarters has been temporarily under the management of C. F. Hauck, sales promotion manager of chemical plants division.

Jackson D. Leonard, a chemical engineer from Metuchen, N. J., has joined R. S. Aries & Associates, Consulting Engineers & Economists, as a senior associate. Mr. Leonard has had fifteen years of varied chemical plant experience in the fields of supervision, engineering, construction, maintenance and development. His early industrial years were spent with General Chemical Co. and later at a number of plant locations with Du Pont and with Merck & Co. He has specialized in cost reduction programs.

Erwin G. Hernreid, chemical engineer with Shell Development Co., is on special assignment at Shell Oil Co.'s Houston refinery where he will spend about a year studying operating problems with the technology and engineering departments.

Vincent W. Uhl was recently named manager of the process equipment divi-

sion of Bethlehem Foundry and Machine Co. Dr. Uhl originally joined Bethlehem in 1946. He held an instructor's fellowship at Lehigh University from 1947 to 1951, receiving his Ph.D. degree from this institution this year.



He was at one time affiliated with the Sun Oil Co. and the Downingtown Iron

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Ralph W. Berger has joined the staff of chemical plants division of Blaw-

Knox Co., assigned to the Midwest branch as a sales engineer. Mr. Berger will devote his time to sales and new project development in the fatty acid and glycerine fields and to specialized engineering on foreign business.



in the fats and oils industry,

Mr. Berger is a chemical engineering graduate of the University of Illinois and has had many years' experience in development and project work in the chemical process industries. For the past five years he has been in charge of fatty acid projects for a large Midwestern engineering-consulting firm.

Robert M. Cornforth has joined the W. M. Barnes Co., of Los Angeles, engineers and constructors to the petroleum and chemical industries, as vicepresident in charge of sales. Formerly he was manager of sales of Houdry Process Corp., Philade'phia. Mr. Cornforth, who holds a B.S. degree from the University of Tennessee, an M.S. from M.I.T., and an M.B.A. degree from Northwestern University, entered the petroleum industry in 1937 as a chemical engineer with Standard Oil Company of Indiana. During World War II, he was assigned by the U. S. Army Corps of Engineers to the Petroleum Administration for War.

V. E. Wellman has been appointed. effective Jan. 1, assistant manager of the intermediate and rubber chemicals department, Calco chemical division of the American Cyanamid Co. Dr. Wellman received his A.B. degree from Phillips University, Enid, Okla., in 1914 and his M.S. (1927) and Ph.D. (1929) from the University of Washington, the latter under a Du Pont fellowship. He was associated with B. F. Goodrich Co. for fifteen years, first as a research chemist, and subsequently as director of purchases, chemicals division and later with R. W. Greeff Co. as assistant sales manager, solvents department. He joined Calco in 1945 and since 1951 has been director of process engineering.

Erwin M. Koeritz is now associated with the chemical division of General Electric Co., Waterford, N. Y., engaged in process development work on silicones and silicone intermediates. Prior to his receiving a Ph.D. in chemical engineering from Georgia Tech in June, 1952, he was employed by Columbia-Southern Chemical Co. Barberton, Ohio.



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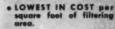
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Christian V. Holland has been named director of chemical research of the



Spencer Chemical Co., Kansas City, Mo. Until he accepted this assignment. Dr. Holland was coordinator of manufacturing facilities for Sterling Drug, Inc. He will make his headquarters at Pittsburg. Kans., Spencer's

general operating headquarters.

Dr. Holland's academic degrees include the Ch.E. from the University of Virginia, Ph.D. from Johns Hopkins University, and M.S. from the Massachusetts Institute of Technology.

As an industrial chemist, Dr. Holland's career has embraced service with Arthur D. Little, Inc., Virginia-Carolina Chemical Corp., Freeport Sulphur Co., Merck & Co. and Sterling Drug. Inc. At Merck, where he held executive posts from 1935 to 1947, Dr. Holland was assistant director of research and development.

During the war, on leave from Merck, Dr. Holland was a member of the United States Strategic Bombing Survey. From September, 1951, until March, 1952, on leave from Sterling, Dr. Holland served as deputy chief of the Drugs. Alcohol and Solvents Branch of the National Production Authority (NPA).

Russell G. Dressler and Loren C. Skinner, of the Bureau of Mines, Louisiana, Mo., have been designated to make a study of synthetic liquid fuels processes and installations in Europe. Dr. Dressler is chief of the gas synthesis demonstration plant, and Mr. Skinner is chief of engineering and design. During the five-week tour, starting early in September, they visited six countries.

E. H. Ten Eyck, Jr., has been appointed to the position of assistant technical superintendent at the Charleston, West Va., plant of Du Pont's polychemicals department. Mr. Ten Evck received his doctor's degree in chemical engineering at the Polytechnic Institute of Brooklyn and joined Du Pont, later in 1949, as an engineer in the plant's technical section. In his new position he will supervise development work on processes for the manufacture of organic chemicals

William R. Millard, formerly associate engineer at the Ames Laboratory and assistant professor of chemical engineering at Iowa State College, is now with Parke Thompson Associates, Kirkwood, Mo.

HETTRICK MADE MGR. CALCO ENG. & DEV.

Ames B. Hettrick has been appointed manager of the newly formed Calco engineering and development department of the American Cyanamid Co.

Educated at Massachusetts Institute of Technology in engineering administration, Mr. Hettrick has been closely identified with the development of the commercially important titanium dioxide pigments. He first joined the Stone & Webster Engineering Corp. in 1928 and in 1931 Southern Mineral Products Corp. as chief engineer and as plant manager in 1934. When this company was purchased by Virginia Chemical Corp. in 1936, he became vice-president and general manager of the new organization. Upon the acquisition of Virginia Chemical's titanium interests by Calco in 1944, he became works manager of the Piney River, Va., plant operation and in 1946 assistant manager of manufacturing for the Calco chemical division.

L. H. Landrum has been named chief process engineer for American Cyanamid's atomic energy division in Idaho Falls, Idaho. Mr. Landrum joined Cyanamid in 1951, being previously employed in the development engineering department of titanium division of National Lead Co. Prior to being affiliated with National Lead, he was associated with Carbide and Carbon Chemicals Corp. and with The Hydraulic Press Manufacturing Co. He received his B.S. and M.S. degrees in chemical engineering from Missouri University and Washington University, respectively.

Alden R. Loosli has been named assistant to the general manager of the American Cyanamid Co., Calco Chemical Division, Bound Brook, N. J., to take effect about Jan. 1, 1953. Loosli attended the University of Idaho and obtained his B.S. degree in physical sciences from the University of Chicago (1937). He began with Calco in 1937 as a student trainee and subsequently held supervisory positions in the various production departments of the chemical and intermediate division. Following a period of sales training in the intermediate and chemical sales division Mr. Loosli was appointed in 1947 assistant sales manager of the rubber chemicals department and in 1950 was named assistant manager of the intermediate and rubber chemicals department after the consolidation of these two departments.

Paul S. Forsyth recently accepted an appointment to the staff of the research and development board, of the Department of Defense, Washington, D. C. He is serving as panel coordinator for the Committee on Equipment and Supplies.

(More About People on page 75)

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- CHEMICAL ENGINEER—B.Ch.E. 1949. Age 26, married. Three years' experience in development and pilot plant operation. Desire position of greater responsibility. Midwest location preferred. Box 9-10.
- TECHNICAL WRITER—B.S.Ch.E. Age 33, family. Offers manufacturing and research experience combined with proven writing ability. Publications in petroleum and chemical engineering journals. Experienced in preparation of operating manuals, ghost-written speeches, technical advertising. Desire responsible writing position, any location. Box 10-10.
- CHEMICAL ENGINEER—B.Ch.E., 1956. Age 23, married. Two years' experience in production supervision. Helped start production in fine and intermediate chemical processes. Desire position in production or engineering related to manufacturing operations with opportunity for advancement. Locate anywhere. Box 11-10.
- CHEMICAL ENGINEER—B.Ch.E. 1948. Age 28, family, veteran. Four years' diversified experience with large oil refinery including laboratory, pilot plant, technical service. Desire challenging position in development or production with smaller expanding company. Box 12-10.
- CHEMICAL ENGINEER—Four years' production experience organic and inorganic chemical manufacturing. Lieutenant, U.S.N.R., release date February, 1953. Desire sales position small or medium sized company, good advancement opportunities. Married, 29 years old. B.C.R. Rensselaer, 1945, one year graduate work University of Michigan. Box 13-10.
- ACADEMIC POSITION—Chemical Engineering Ph.D. Age 14, family. Active member A.I.Ch.E. Seek teaching position with responsibility and opportunity. Twelvemonth basis preferred. 7½ years' teaching, industrial, and consulting experience. Publications. Excellent references. Available February or June, 1953. Box 14-16.
- CHEMICAL ENGINEER—B.S. 1942. Veteran (no reserve). Age 31, family. Seeking challenging position with future. Seven years' progressive diversified experience. Alcohol, rayon, plastics. Government service. Prefer Eastern U. S. Present salary \$6000. Box 15-10.

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- CHEMICAL ENGINEER—B.S., M.I.T. 1951. Chemical engineering and business administration. B.S.Ch.E., Columbia University, 1952. Desire position—opportunity primary consideration. Bog. 23-10.

PEOPLE

(Continued from page 73)

Milton Devore has recently joined the staff of the Fluor Corp., Ltd., Los Angeles, as a process engineer. For the past seven years he was with U. S. Industrial Chemicals Co. in research and development. Prior to that, he spent a year on the Manhattan Project with the Kellex Corp. and during the war was a civilian inspector with Chemical Warware Service. He took his B.Ch.E. at Cooper Union, class of 1940.

Richard W. Deboney development engineer, from 1950 to 1952, at Carbide & Carbon Chemicals Co., Oak Ridge, Tenn., is now associate professor of chemical engineering at Vanderbilt University, Nashville, Tenn. He is a consultant to the Tennessee Products & Chemical Co. and the University of Louisville Institute of Industrial Research.

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PEOPLE

(Continued from page 75)

MUNRO, MONSANTO'S PLANT MGR., AT SEATTLE

The appointment of W. S. Munro as plant manager of Monsanto Chemical Co.'s Seattle plant was announced recently.

Murro, a native of Oakland, Calif., received a B.S. degree in chemical engineering from the University of Washington (1935). Before joining Monsanto he was employed by Standard Oil Co. at Richmond, Calif., as a chemist. He joined I. F. Laucks, Inc., in 1941 as a chemical engineer and remained in this capacity when Monsanto acquired the Laucks organization in 1944. Since 1947 he has been chief chemical engineer of the Western division.

Dorothea Barcus Thomas, formerly with Shell Oil Co., San Francisco, Calif., and later at its Martinez refinery, is now with Gates Rubber Co. engaged in textile research.

Shelby A. Miller, professor, department of chemical engineering, University of Kansas, is spending this school year at the University of Durham at Newcastle, England, as a Fulbright lecturer. During his absence he will be replaced by Frank C. Fowler as visiting professor of chemical engineering. Dr. Fowler is a consulting engineer in Kansas City, Mo. He was a professor of chemical engineering at the University of Oklahoma and prior to that he was with the Phillips Petroleum Co. Among his other activities he is at present a consultant to the Midwest Research Institute on problems in petroleum technology.

C. Fred Gurnham is the new head of the department of chemical engineering at Michigan State College, East Lansing. Dr. Gurnham has more than twenty years' experience in industrial and educational capacities. He went to M.S.C. from Tufts College, Mass., where he had headed the chemical engineering curriculum for four years. He has worked as an assistant professor of chemical engineering at Pratt Institute; as chemical engineer for the Whitnev Blake Co. and other industrial concerns, and as an engineering consultant. Dr. Gurnham holds degrees from Yale University and New York University.

Chemical Engineering Progress has recently received news of the death of the following members:

Richard P. Horner, Atlantic Refining Co., Philadelphia, Pa.

Arthur L. Mohler, chlorine area superintendent, Columbia Southern Chemical Corp., Barberton, Ohio.

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INDEX OF ADVERTISERS

Po	ge
American Instrument Co., Inc	58 66 68 25
Badger Process Div., Stone & Webster Engineering Corp. Bartlett & Snow Co., The C. O. Brookfield Engineering Labs., Inc. Brown Fintube Co.	24 20 70 18
Climax Molybdenum Company Condenser Service & Engineering Co., Inc Corning Glass Works Crone Company	13 64 56 49 4 77
Dorr Company	62 10
Electro Chemical Engineering & Mfg. Co	73
Fansteel Metallurgical Corp	50 12 51
Food Technology, Inc.	66 29 57
Inside Front Cover, 16, 27,	33
Girdler Corp. Glycerine Producers, Inc. Great Lakes Carbon Corp. 5, Gump Co., B. F.	7 47 78 74
Hammel-Dahl Company Hardinge Company, Inc. Haveg Corp. Hilliard Cerp. Hills-McCanna Co.	42 62 15 73 19
Instruments, Inc.	70
Johns-Manville	28 71
Knight, Maurice A	67
Lapp Insulator Co	38 76 27
Martindale Electric Co	76
National Carbon Co., A Division of Union Carbide and Carbon Carp	30 70
P & L Welding & Machine Warks, Inc Pennsylvania Salt Mfg. Ce. Petro-Chem Development Co., Inc Prizer & Co., Inc., Chas. Prater Pulverizer Co. Process Controls	14

Advertising Offices

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Los Angeles 15-Richard P. McKey, Dist. Mgr., 1206 S. Maple Ave., Prospect 3919.

Page
Read Standard Corp 61
Republic Flow Meters Co
Rohm & Haas Co
Shriver & Co., Inc. T
Sparkler Manufacturing Co
Spray Engineering Co
Sterling Electric Motors
Stone & Webster Engineering Corp., Badger
Process Div
Struthers Wells Corp 53
Swenson Evaporator Co., Div. of Whiting
Corp Back Cover
Taber Instrument Corp
Toylor & Co., W. A

Thermal Syndicate, Ltd	26
Union Carbide and Carbon Corp.,	77
National Carbon Co	30
U. S. Instrument Corp	60
U. S. Stoneware Co	59
Vapor Recovery Systems Co	
Welsbach Corp	21
Chemical Corp	55
Whiting Corp., Swenson Evaporator Div.,	
Bock Co	ver
Wiggins Gasholder Div	33
Wysamont Co	54



CONTENTS ANY DISTANCE AWAY

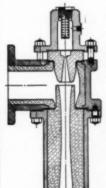
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Stainless steels, Monel metal, Beryllium copper, Ni-Resist, PMG metal, hard lead, special bronzes, Hastalloy, and Illium are but a few of the special metals which find their way into our equipment. Carbon is used extensively as a lining material, and many plastics including Teflon and synthetic materials are used for making complete Evactors.

Consult our engineers for high vacuum equipment carefully designed for your specific conditions, and constructed of materials selected for your particular conditions.



Main Office: 751 Central Avenue, Westfield, New Jersey New York Office: 17 John Street, New York 38, N. Y.

CHILL-VACTORS

STEAM JET EVACTORS

CONDENSING EQUIPMENT

THE FOURTH DICALITE PLANT



...will add approximately 80% increased production capacity for Dicalite calcined and processed filteraids and fillers

The new plant of the Dicalite Division, Great Lakes Carbon Corporation, at Lompoc, Calif., is now in volume production at a continually increasing rate. It represents over 5 years of engineering, design and construction, and is the largest complete unit for processing diatomite built in the last 22 years. Full designed output will add approximately 80% increased production capacity for Dicalite calcined and processed filteraids, fillers and other materials.

This increased production capacity insures a

plentiful supply of Dicalite products for the future. Users can be confident of dependable delivery, with four plants in operation, chances of interrupted supply are greatly reduced.

Advanced design of the new plant has afforded greater operating flexibility and extended processing ranges. Specifications for performance and quality of each product are readily maintained. Research data are being accumulated to aid in developing new and improved Dicalite products for future industrial use.

DICALITE DIVISION GREAT LAKES CARBON CORPORATION



NEW YORK 17 . CHICAGO I . LOS ANGELES 17



VULCAN DESIGNS ITS OWN MACHINES

FOR

PRECISION FABRICATION

Tolerance standards developed at Vulcan are widely used by engineers in the chemical process industries.

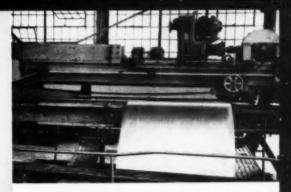
A prime reason for this is Vulcan's use of specialized machine tools capable of holding close tolerances in forming operations.

These machines were built by Vulcan to meet the exacting requirements of chemical process specifications.

Vulcan will assume complete responsibility for the design and precision fabrication so necessary in process equipment.

Inquiries will receive prompt attention.

VULCAN



A horizontal seam-rolling machine is used to smooth, harden and round up copper shells to closer tolerances than can be done by hand. Designed and built by Vulcan mechanical engineers, it can handle material up to ½ inches thick and shell sections up to 16 feet in length.



Turning callars on heads and trays is everyday work for this machine. Callars turned are uniform and the trays are kept round and flat. Precision turning of this type greatly expedites assembling and fitting the trays into the tower shell sections. In the finished lower it assures level trays for maximum efficiency and trouble-free operation.



VULCAN MANUFACTURING DIVISION

Na VULCAN COPPER & SUPPLY CO., General Offices and Plant, CINCINNATI 2, OHIO NEW YORK BOSTON PHILADELPHIA SAN FRANCISCO VICKERS VULCAN PROCESS ENGINEERING CO., LTD., NONTREAL, CANADA

A specially-built bar-bending mathine can cold form bars up to two inches by four inches into circles thirty inches in diameter and up. These circles are used for reinforcing and stiffening rings, backing flanges, lap callars and for internal tray support rings. Rings or flanges formed on this machine are held to a close tolerance for roundness and flatness.

DIVISIONS OF THE VULCAN COPPER & SUPPLY CO.

